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MINING BY THE TOP-SLICING METHOD, WITH SOME NOTES ON SUBLEVEL CAVING

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MINING BY THE TOP-SLICING METHOD, WITH SOME NOTES ON SUBLEVEL CAVING[1]

By Chas. F. Jackson[2]

INTRODUCTION

This paper is one of a series dealing with mining methods and costs, prepared and published under the sponsorship of the United States Bureau of Mines and made possible through the cooperation of many mining companies in the United States and foreign countries.

The preparation of this paper follows a field study of top-slice mining during which the author visited and discussed with operating officials a large number of iron mines in the Lake Superior region. During this study special note was made of changes in top-slicing practice during the past decade, prior to which the author had acquired several years experience with the method through active connection with a number of mines employing top slicing.

The data presented have been obtained from papers previously published by the bureau dealing with individual mines, from the technical press, and from information furnished by the mining companies during the recent field study.

ACKNOWLEDGMENTS

The author desires to express his appreciation of the courtesy extended by the officials of the mining companies in affording opportunity for underground study and in furnishing the operating data requested for use in this paper.

PRODUCTION

Complete data regarding the annual tonnage of ore mined by top slicing in the United States are not available. Although most of the ore mined on the Mesabi Iron Range in Minnesota is produced by open-cut methods, a considerable tonnage is mined underground, practically all of which is done by top-slice methods. This method is also employed in some of the mines of the Vermilion and Cuyuna Ranges in Minnesota and some of the mines of the Marquette and Menominee Ranges in Michigan.

During 1929, shipments of iron ore from the Lake Superior region amounted to 66,157,359 gross tons. During that year approximately 12,000,000 tons were mined by the top-slicing method and 6,500,000 by sublevel caving, a total of about 18,500,000 tons by both methods. Bearing in mind that there is a difference between tons mined and tons shipped during any given year, it may be stated that the tonnage mined by these two methods was, therefore, roughly 25 to 30 per cent of the total 1929 iron-ore production from this region.

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[1] - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6410."

[2] - Principal mining engineer, U. S. Bureau of Mines.

DEFINITIONS

Top Slicing (see fig. 1).- The term "top slicing" is commonly applied to that method of mining in which the ore is extracted by a series of timbered slices, beginning at the capping; the slice is caved, bringing down the capping to the floor of the slice; the succeeding lower slices are mined up to the overlying mat or gob, consisting of an accumulation of timber from the upper slices and broken capping, which follows the mining progressively downward.

The term has also come to be applied to the mining of ore bodies only one slice thick, by a series of timbered slices one beside the other. The timbers are blasted out, bringing the capping down to the floor, succeeding slices being driven alongside those already caved (fig. 2).

In the Bureau of Mines classifications of mining methods, top slicing has been placed under the heading of "Caved Stopes." The method differs fundamentally, however, from the caving methods of mining in which the breaking of the ore itself is accomplished by caving action induced by undercutting, while in top slicing the ore is broken by the ordinary methods of drilling and blasting, and only the capping is broken up by caving.

Sublevel Caving (see fig. 3).- This term is here applied to a combination of slicing and caving in which mining starts below the capping or top of the ore body as in top slicing. In this method, however, the vertical interval between sublevels or slicing levels is greater than in top slicing; timbered slices are driven, but instead of ore being taken out to the mat above as in top slicing, a back of ore is left between the top of the slice and bottom of the mat; after the slice has reached the mining limit, the back of ore between it and the mat above is removed by caving, starting at the end of the slice and retreating toward the entrance. This method possesses so many features in common with top slicing that it will be briefly discussed in this paper. While both methods are applicable to much the same mining conditions, top slicing requires that the gob shall come down immediately upon removal of the support from below without hanging up, while sublevel caving requires that the gob shall hang temporarily while the back of ore is caved and removed from beneath it. Top-slicing is applicable to thinner ore bodies and can be used under a gob composed of finer waste material than can sublevel caving.

Main Levels or Haulage Levels (see figs. 1, 3, 5A, 7, 8, 15, 21, 24).- Main or haulage levels are the main extraction levels on which the ore is hauled to the shaft. These levels and the shaft constitute the preliminary development of the mine.

Sublevels or "Subs" (see figs. 1, 3, 5, 7, 8, 15, 17, 18, 21, 24).- Above the haulage level are the sublevels, on which slicing operations are conducted. They may or may not be connected directly to the shaft but are connected with the main haulage level by a series of chutes and manway raises.

Sublevel Interval.- The sublevel interval is the vertical height measured from floor to floor of adjoining sublevels.

Slice (see figs. 1, 2, 3, 5, 7, 8, 15).- In top slicing, the stoping unit is termed a "slice." This slice is virtually a timbered drift driven under and up to the capping or caved mat above. In length it extends from the raise, opening set, or other starting point to the margin of the ore, caved ground, or predetermined mining limit. In sublevel caving, it is a timbered drift from which caving is conducted on the retreat.

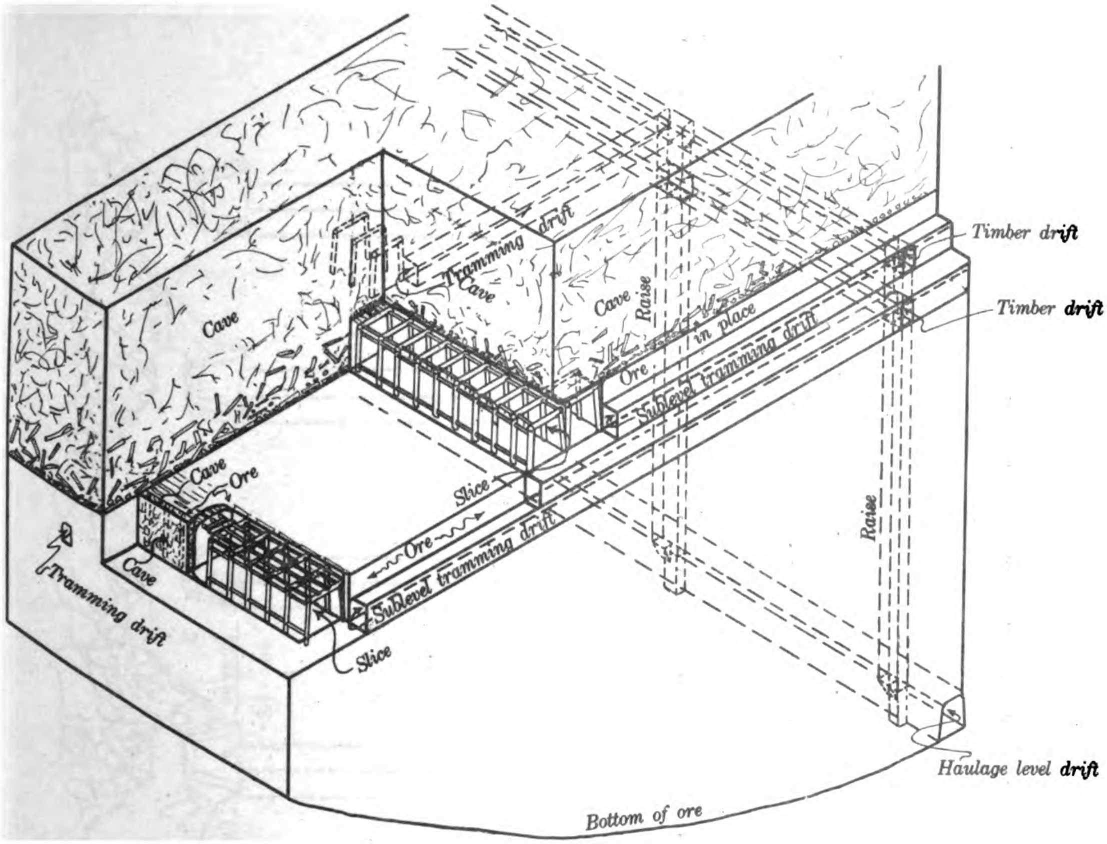
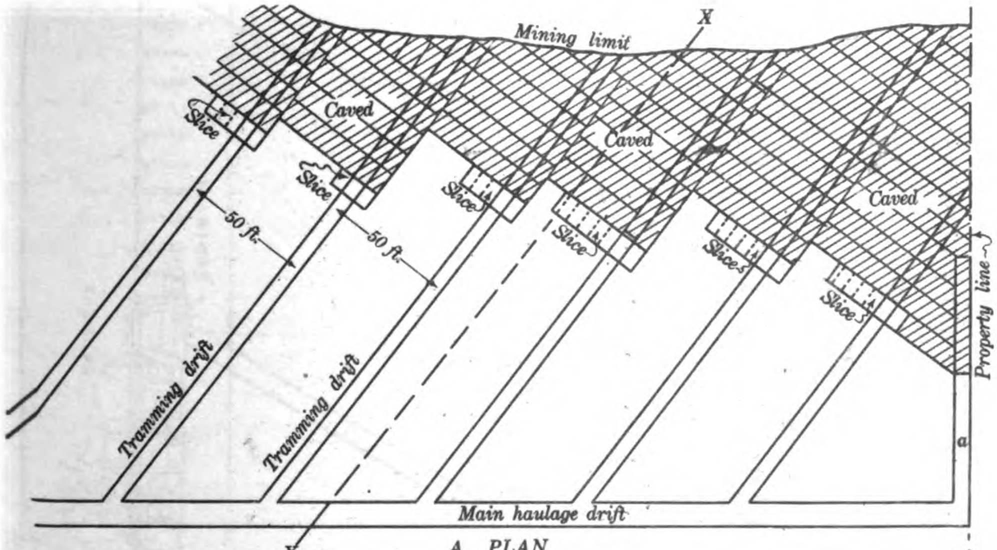
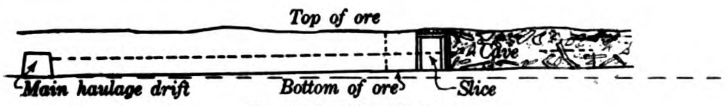


Figure 1. – General scheme of horizontal top slicing



A. PLAN



B. SECTION X–X

Figure 2. – Top slicing in flat ore body one slice thick

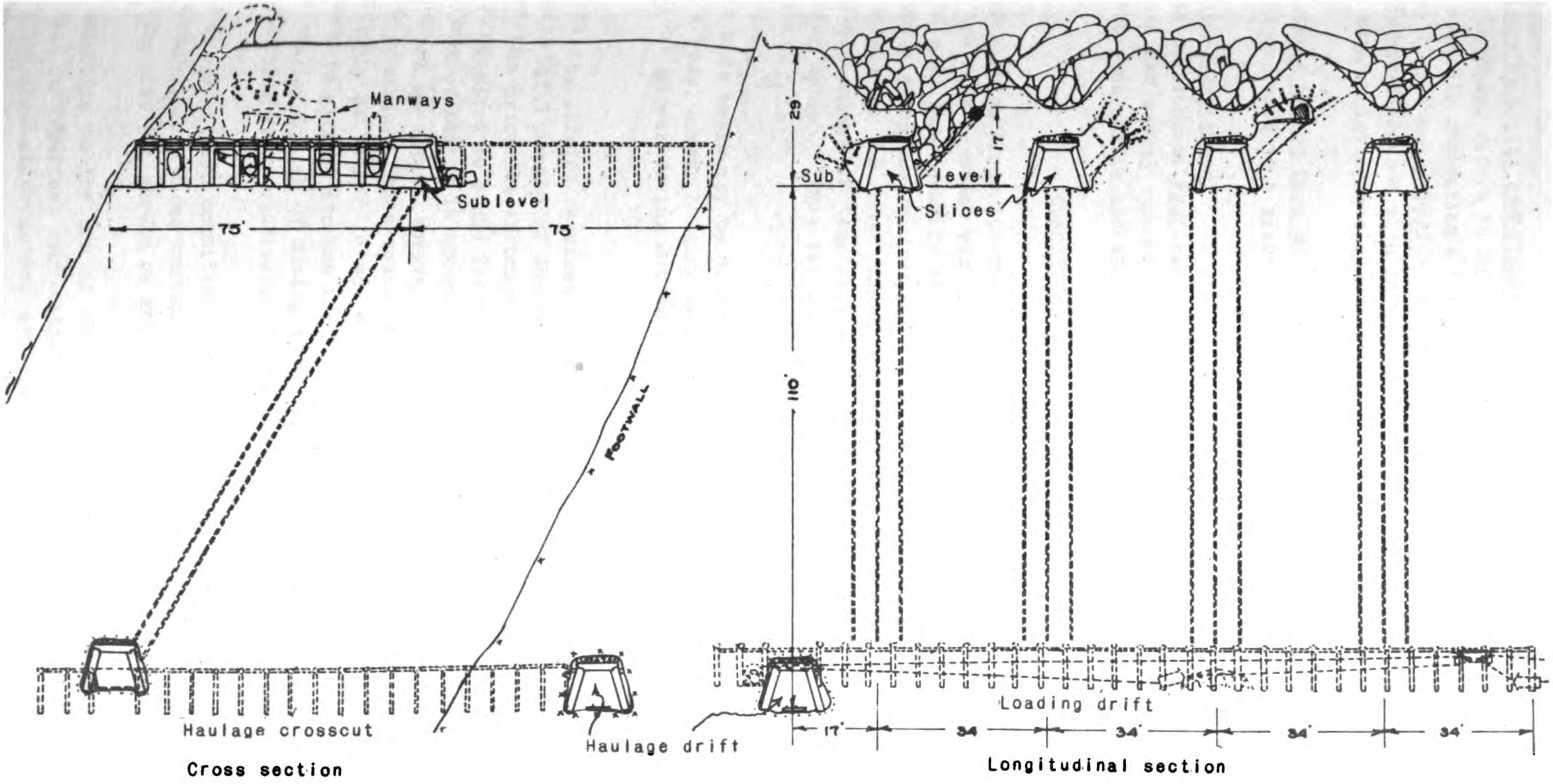


Figure 3.- Sublevel caving with scraper loading drift

Tramming Drifts and Timber Drifts (figs. 1, 2, 5, 7).- The term "tramming drifts" as used in the paper, refers to development drifts on the sublevels. Timber drifts are sublevel drifts usually connecting a line of raises or crosscuts therefrom, and used principally for handling timber and supplies on the sublevels. As will be seen later, tramming and timber drifts are dispensed with in some cases. Where timber drifts are employed they constitute the main sublevel development openings.

Opening Set or Open Set.- The term "opening set" is applied to the first set of timber at the entrance to a slice and is the key set of the slice.

Stope Development.- "Stope development" and "stope preparation" are terms used to designate the development required to block out the ore in preparation for slicing. It consists of chute and manway raises to the sublevels, tramming and timber drifts as above defined, but excludes shafts and all main level development.

CONDITIONS SUITED TO TOP-SLICE MINING

Top slicing finds its chief application in the mining of fairly wide ore bodies of a character too weak to stand without support over other than short spans and having a weak capping which will cave readily when the support is removed and fill the excavated space tight. A capping which breaks into large blocks which arch over or hang up so as to leave large open spaces in the cave constitutes the greatest source of danger in top slicing, though a certain amount of temporary arching and hanging up is desirable for the related sublevel caving method. Thus for successful top slicing, top weight or vertical pressure is necessary.

The side walls may be either weak or strong. If the ore occurs in the form of a narrow dipping body, a weak hanging wall is desirable for top slicing, since a strong hanging wall may prevent proper caving due to arching over of blocks of broken capping between the walls.

Since top slicing requires the use of considerable timber and lagging, it is essential that a plentiful supply of cheap timber be available; that is to say, the supply must be assured and the price low in comparison to the value of the ore to be mined. Since slice timber is only required to stand for a relatively short time and is then blasted out, a somewhat poorer grade of timber is acceptable than would be required for more permanent support. The timber should be tough, however, and capable of undergoing considerable crushing and bending before breaking; hence round green timber with the bark on is usually employed. If an adequate supply of timber is not available or its cost is too high in relation to the value of the ore to warrant its use for the sake of securing high extraction and low dilution of the ore, a caving system of mining would suggest itself for mining the type of ore body to which top slicing would otherwise be applicable.

Obviously a third condition for top slicing is that disturbance and caving of the surface are permissible. Under certain deep-mining conditions, surface subsidence might not occur for a long time but should be anticipated eventually.

In addition to the use of the top-slicing method of mining for mining an entire ore body, it has an important application in the extraction of pillars between stopes previously mined by some other method and for robbing operations in caved or badly broken ground. Where ground is so badly broken that it is unsafe or impracticable to mine upward

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by any of the overhand stoping methods, it may often be mined in safety and at reasonable cost from the top downward by top slicing or by sublevel caving.

ADVANTAGES AND DISADVANTAGES OF THE TOP-SLICING METHOD

Advantages

1. Top slicing is a safe method of mining heavy ground which can not be economically and safely mined by overhand stoping methods, and is economical where timber is plentiful and reasonable in cost.

2. A very high extraction of the ore is possible with practically no dilution from the capping and walls.

3. Under proper supervision the method is safe, as evidenced by the many excellent safety records made by mines employing it.

4. Where market conditions are such that the mine is faced with occasional shutdowns, the stopes or slices may be blasted down so that the ore body remains in good condition for resumption of operations on short notice even after idleness of considerable duration, although development headings may require considerable repair work and maintenance if close to the caved ground.

5. Although considerable preparatory development is required prior to beginning slicing operations, once this development is well started a considerable tonnage of ore is produced therefrom, and in the type of ore to which top slicing is commonly applied the cost of development ore is not greatly in excess of that of ore from slicing (see items 6 and 7 under "Disadvantages"). At one property visited it is estimated that ore from development headings costs about 20 per cent more than that produced from slices.

6. Top slicing can be employed under sand and other loose surface material and does not require as clean a mat as does sublevel caving. If fine waste is mixed with the gob in sublevel caving, the ore is apt to be considerably contaminated thereby (see item 10 under "Disadvantages").

Disadvantages

1. If timber and lagging are not in adequate supply and are expensive, the top slicing method has obvious disadvantages from the standpoint of cost.

2. The method is more expensive than some other methods which may be used under similar conditions, though with other methods a lower ore extraction and higher dilution of the ore is apt to result.

3. Where it is necessary to protect the surface against subsidence this method would seldom be applicable, although under certain deep-mining conditions where the ore body is thin it might still be employed. Sometimes fault planes, jointing, or other lines of weakness in the capping may cause subsidence at some distance from the area immediately over the mine, while in other cases only the area directly over the excavation may be affected.

4. Ventilation is not simple in top slicing and in deep mines working under a thick mat of timber; in heavy sulphide ores which oxidize when exposed to the mine air with attendant generation of heat and possibly of gas, ventilation may be an important considera-

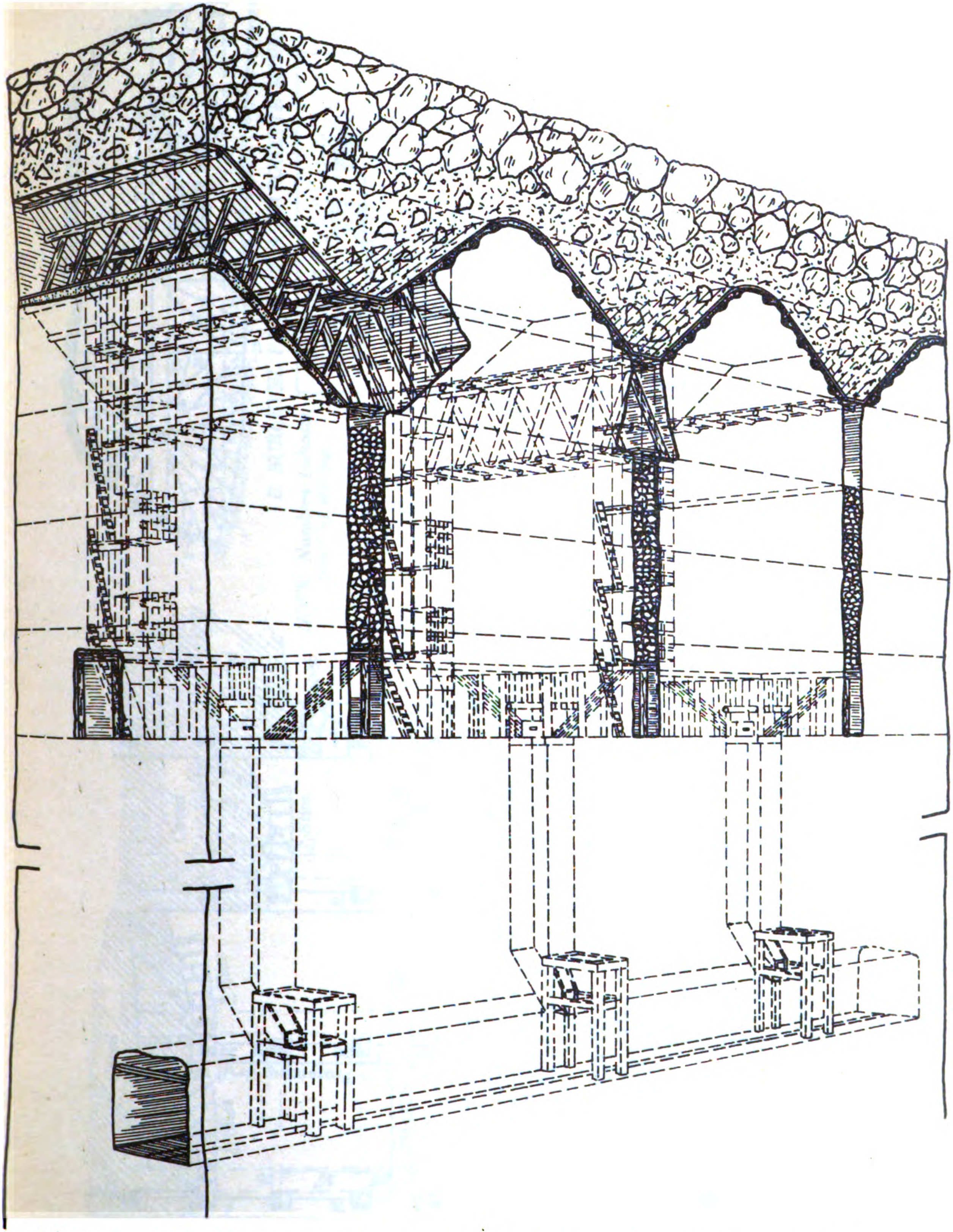
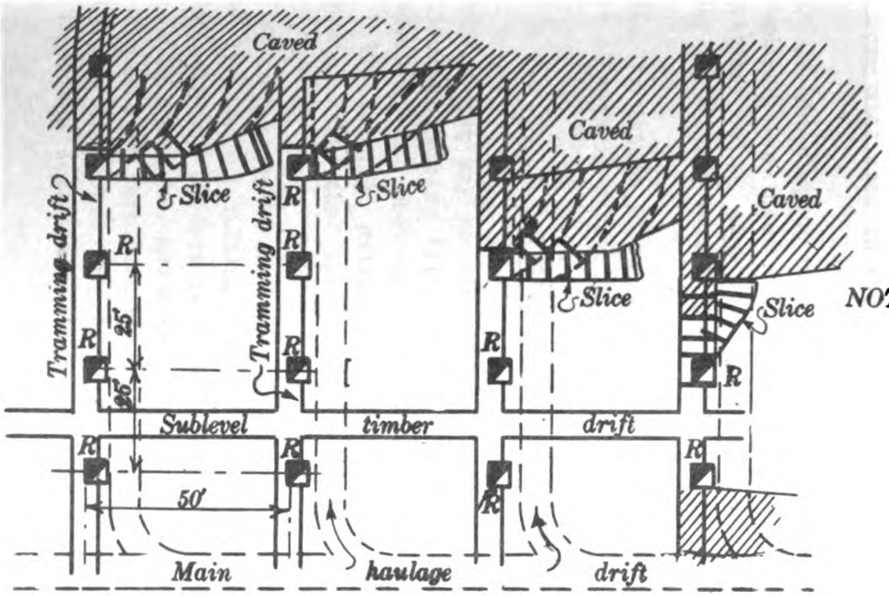
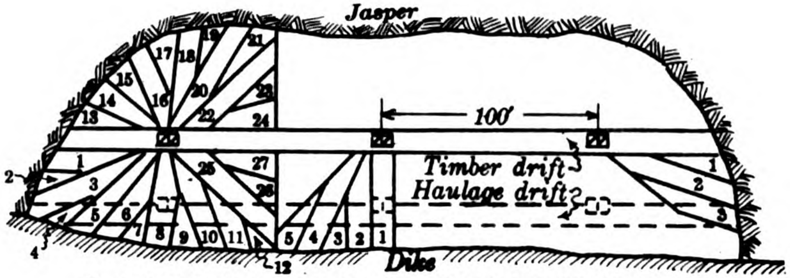


Figure 4.- Perspective sketch of Coronado incline top-slicing mining method

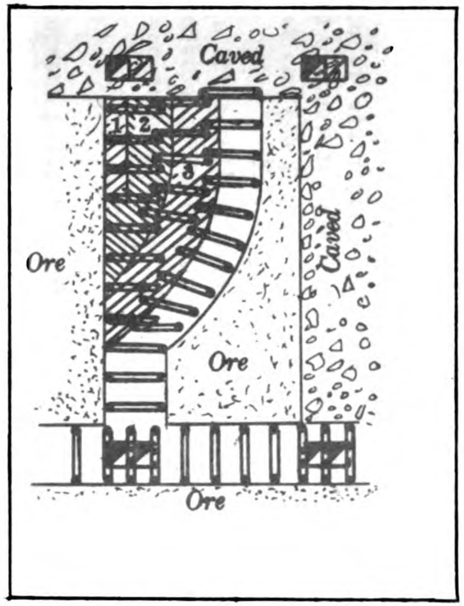


A. SUBLEVEL PLAN AT A MESABI MINE

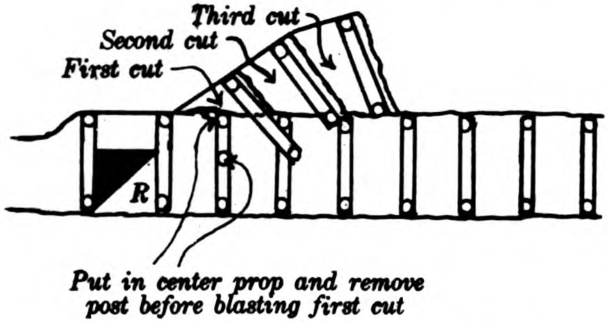


B. SUBLEVEL PLAN AT A MARQUETTE MINE

NOTE: Numbers indicate order of slicing



C. PLAN FOR SUBLEVEL CAVING, GOGEBIC RANGE


Third cut
Second cut
First cut
R
Put in center prop and remove post before blasting first cut

D. TIMBERING RADIAL SLICE, PLAN

Figure 5. – Radial slicing; sublevel plans

tion. In some cases the only solution is to serve each slice with a small, individual, booster fan. Forced ventilation from the surface with fans of large capacity is used in some of the deeper mines.

5. Where large amounts of old timber accumulate, as often occurs in top-slice operations, a certain fire hazard undoubtedly exists. Fortunately many mines employing top slicing are wet or decidedly moist and gob fires are not of common occurrence.

6. In order to obtain a large output, a considerable number of working places are required. Except under ideal conditions, this usually means that working places are scattered over a considerable area and connected by a correspondingly large amount of development openings.

7. The period of development prior to production from slicing is relatively long. Rate of output can not be suddenly increased to meet market demands unless development is considerably in advance of normal production requirements.

8. Timbering and covering down the slices consumes a large part of the shift, which reduces the available time for breaking and mucking. Thus the usual equipment consisting of rock drills and scraping equipment is idle much of the time.

9. Handling of timber, lagging, boards, and wire fencing is a large item of expense in top-slice mining, since these materials are used in large quantities and are often transported long distances in the mine.

10. If the capping breaks in large blocks which wedge together so as to leave a large open space below them, sudden collapse presents a serious element of danger to the slicing operations below, especially if there is not a good cushion of gob between the open space and the top of the active slice (see item 6 under "Advantages").

11. The method is not adapted to sorting of waste in the stopes or to leaving small horses of rock in place.

VARIATIONS OF THE TOP-SLICING METHOD

Top slicing may be classified on the basis of the inclination of slices as (1) flat or horizontal slicing (figs. 1, 2, 5, 6, 7, 8, 15, etc.), and (2) inclined slicing (fig. 4) depending upon whether the slices are driven level or at an inclination from the horizontal. The inclined method was evolved to eliminate hand-shoveling by driving the slices at such an angle that the broken ore would run to chutes by gravity.

Flat or horizontal methods may be further subdivided on the basis of direction of slicing into (1) parallel slicing (figs. 1, 2, 6, 7, 24), and (2) radial slicing (figs. 5 and 8). In radial slicing the ore is scraped directly from the face into chutes. In parallel slicing the ore may also be, and often is, scraped directly to chutes (fig. 24), but in other instances it is scraped into cars (figs. 1, 2, 7, 12). Each method has its peculiar application, but scraping into cars is generally used to-day only for slightly dipping, wide, thin ore bodies where the development in rock required for scraping direct to chutes would be prohibitive.

Top slicing might also be classified, on the basis of the method of handling and loading ore, into (1) hand-loading to cars, (2) scraper-loading to cars, (3) scraping direct to chutes, and (4) gravity handling to chutes (inclined top slicing).

Based on the manner in which the ore body is divided up for mining, we have (1) longwall slicing, in which a series of slices are driven end to end (figs. 1, 2, 7) from a number of suitably arranged tramming drifts, starting at the margins of the ore body, caving, and retreating therefrom; and (2) panel or block top slicing, in which the ore body is divided into a number of blocks or panels each having a central chute and manway raise (fig.6).

REPRESENTATIVE TOP-SLICING OPERATIONS

A. Lake Superior Iron Ore Districts

The first use of top slicing in the Lake Superior Region is believed to have been for the extraction of ore left in pillars between stopes which had been mined by open-stope or square-set methods. It is reported that it was first introduced in this region at the Lake Angeline mine, Ishpeming, Mich., by Capt. Thomas Walters. The method originated in England.

1. Mesabi Range

Following the earlier use of more wasteful methods of mining on the Mesabi Range and with the growing realization of the value of Mesabi ores, top slicing, which had been successfully employed for pillar recovery, was soon adopted as the standard method of mining. Mesabi Range ore bodies are admirably adapted to mining by top slicing where underground methods must be used. While by far the greater proportion of the output on this range is from open-pit mines, there are also many underground operations.

In this district the ore bodies usually lie at comparatively shallow depths and are in the form of relatively thin, broad and flat-lying, elongated basin-shaped deposits. The boundaries are usually quite sharp and well defined, though gradations between ore and low-grade material within the ore bodies often occur.

The wall rock is taconite, a hard ferruginous chert. The region is covered by glacial drift from a few feet to 150 feet or more in thickness and the immediate capping of the ore bodies may be either glacial drift, paint rock, slate, lean ore, or taconite. The glacial drift or surface material varies from fine sand, clay, or gravel to large bowlders imbedded in the finer material. The taconite capping is hard, but unlike the underlying and wall taconites is usually partly leached and contains slips and joints which allow it to break and cave readily when undercut. Sometimes the ore must be mined out from beneath for a width of two or three slices before the taconite capping will break, but once a cave is started the following slices cave readily. The ore itself consists of soft hematite and limonite.

Top slicing has been successfully done under a wet quicksand cover, though great care must be exercised. At one such operation with which the author was familiar it was customary to leave a few feet of ore against the sand for protection in mining the first slice. Hay was packed in over the lagging, and before blasting down the slice the floor was covered with a mat of hay. Due to uneveness of the sand-ore contact, a sand break would occasionally occur which would fill drifts and raises for several hundred feet. Such occurrences were rare, however, and top slicing was carried on for some years under these conditions without serious accident.

Three principal types of ore bodies are mined by top slicing on the Mesabi Range:

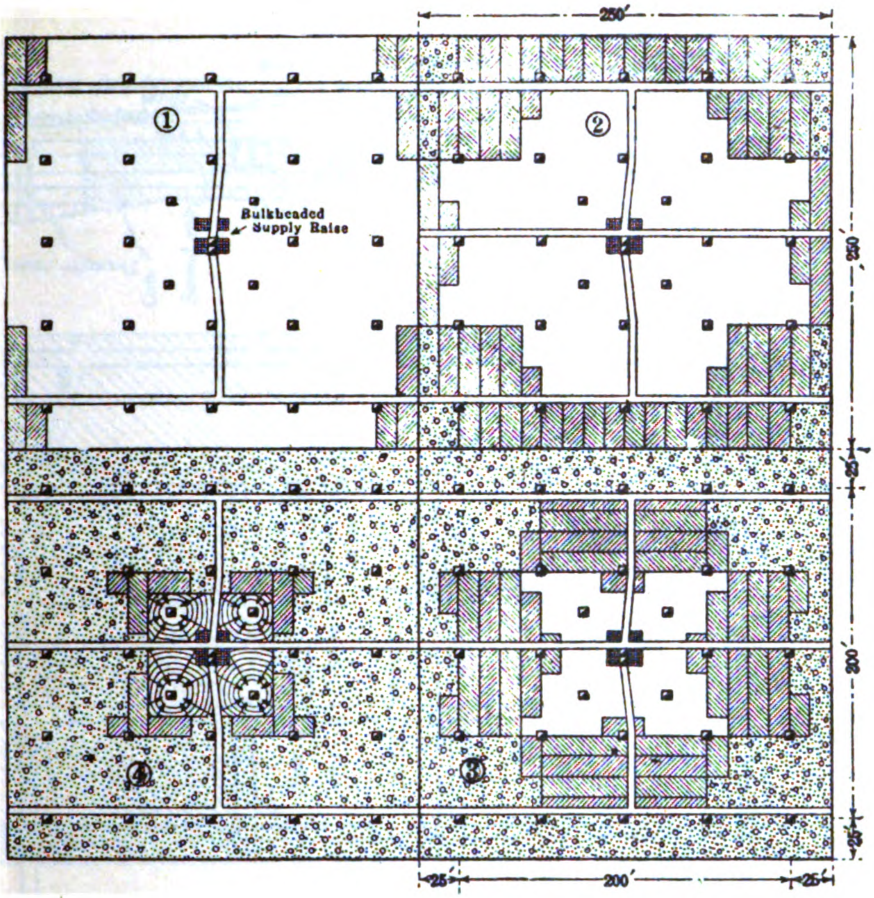
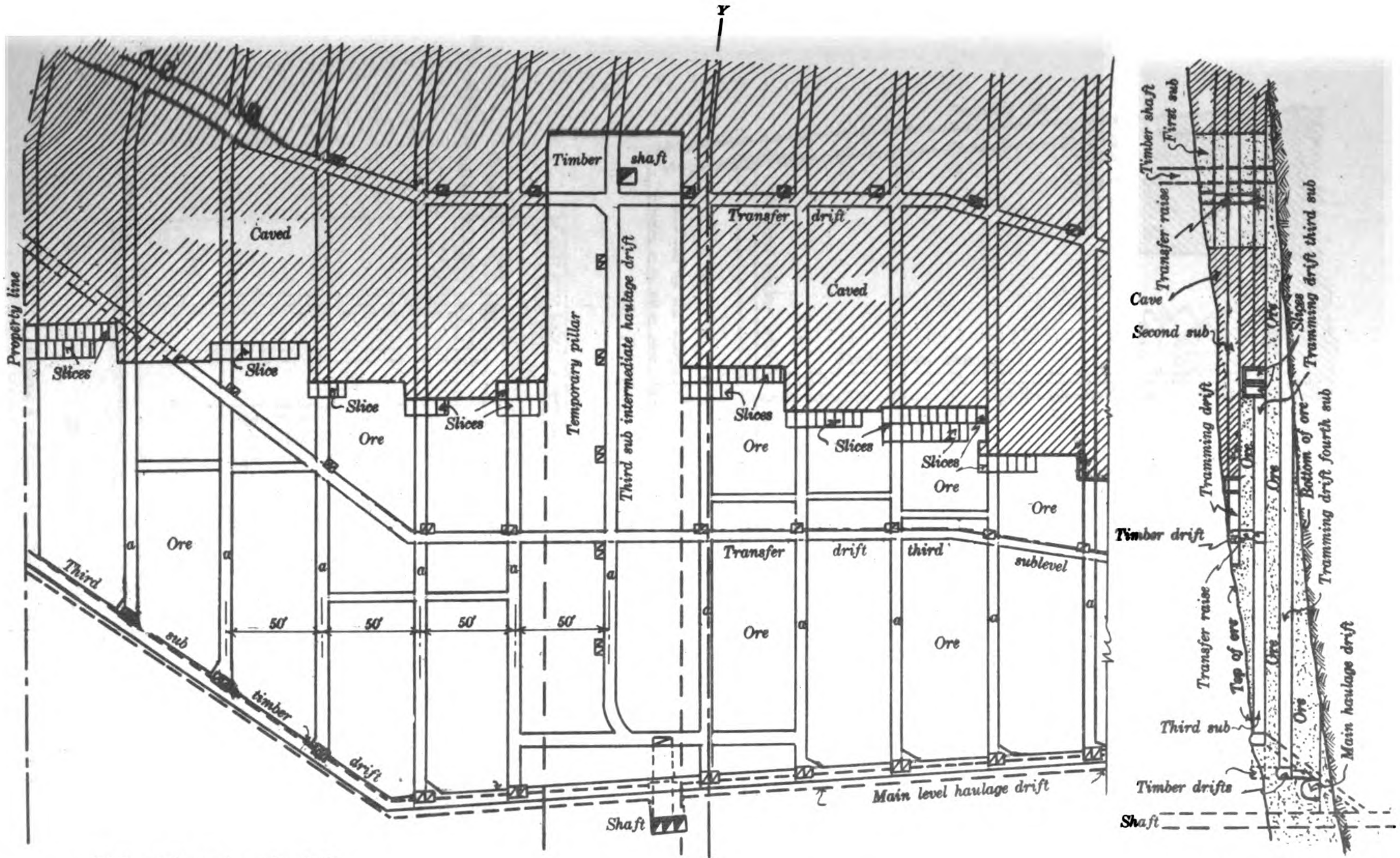


Figure 6.- Plan of successive steps in block method of top slicing

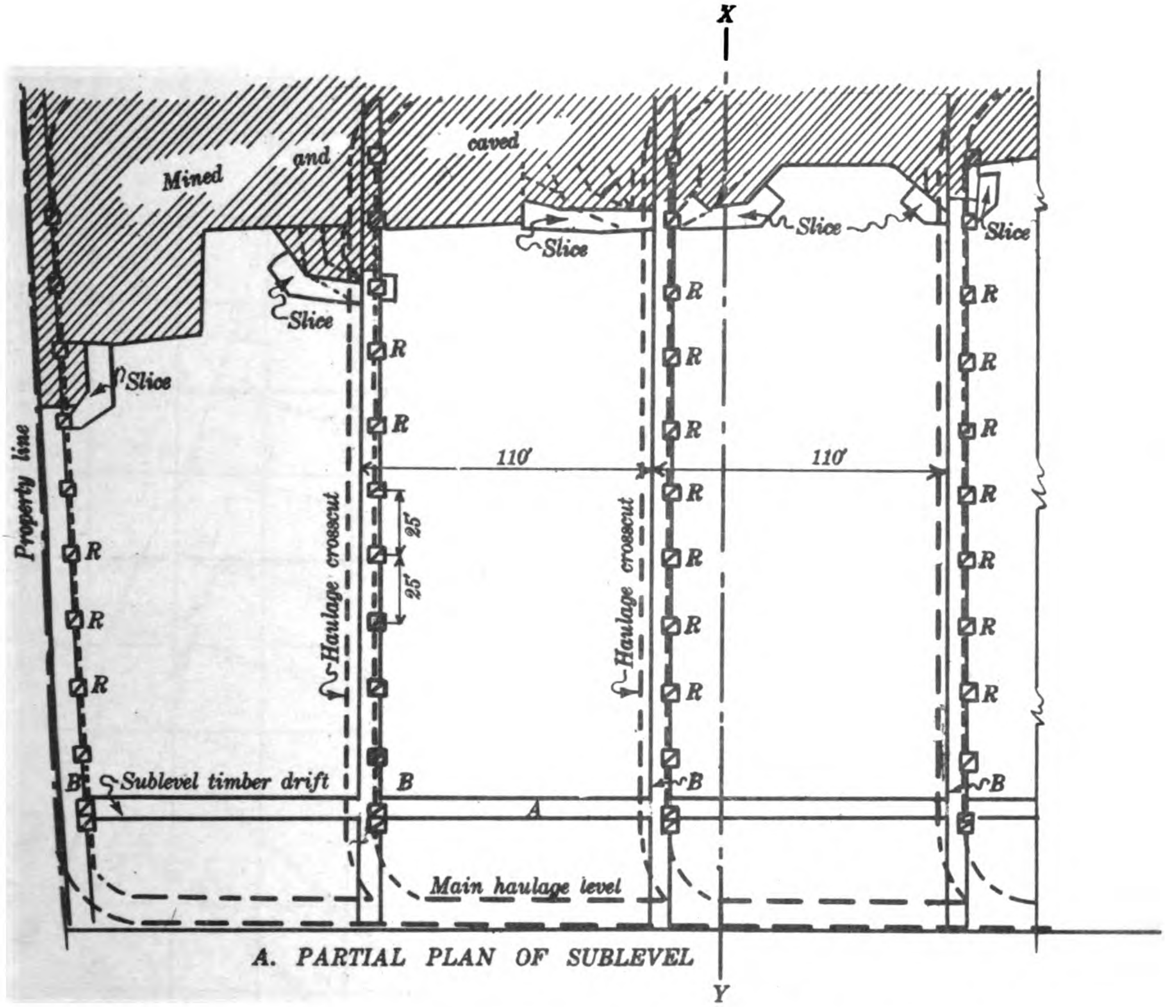


NOTE: a indicates tramming drift

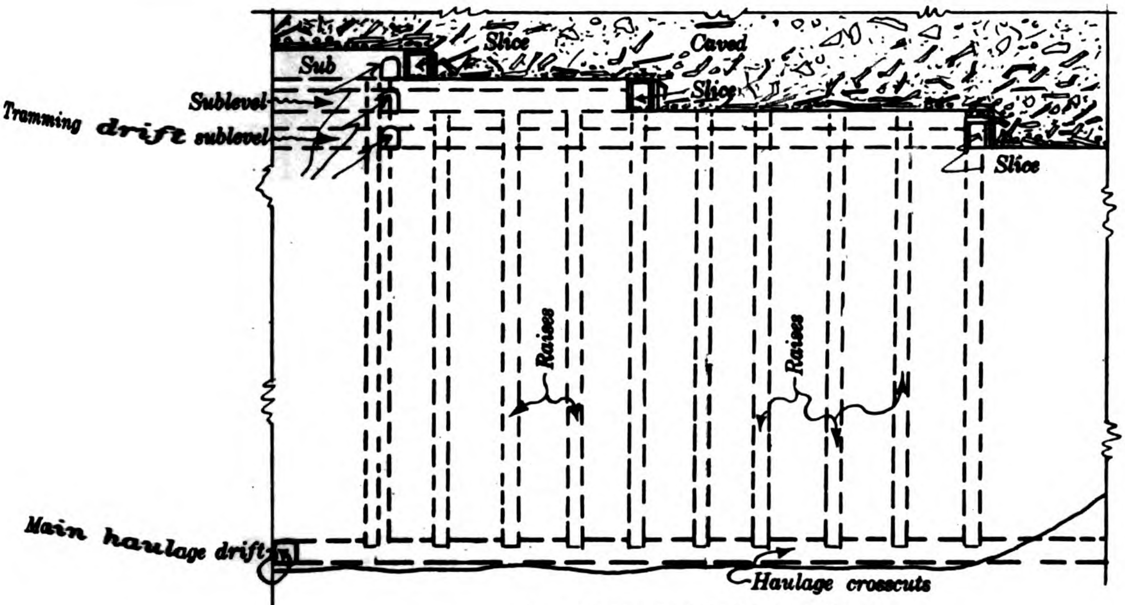
A. PLAN OF PART OF THIRD SUBLEVEL

B. CROSS SECTION ON X-Y

Figure 7.– Parallel top slicing, scraping to cars; flat dipping ore body, 2 to 4 subs thick



A. PARTIAL PLAN OF SUBLEVEL



B. CROSS SECTION ON X-Y

Figure 8.—Radial top slicing to chutes; thick ore body

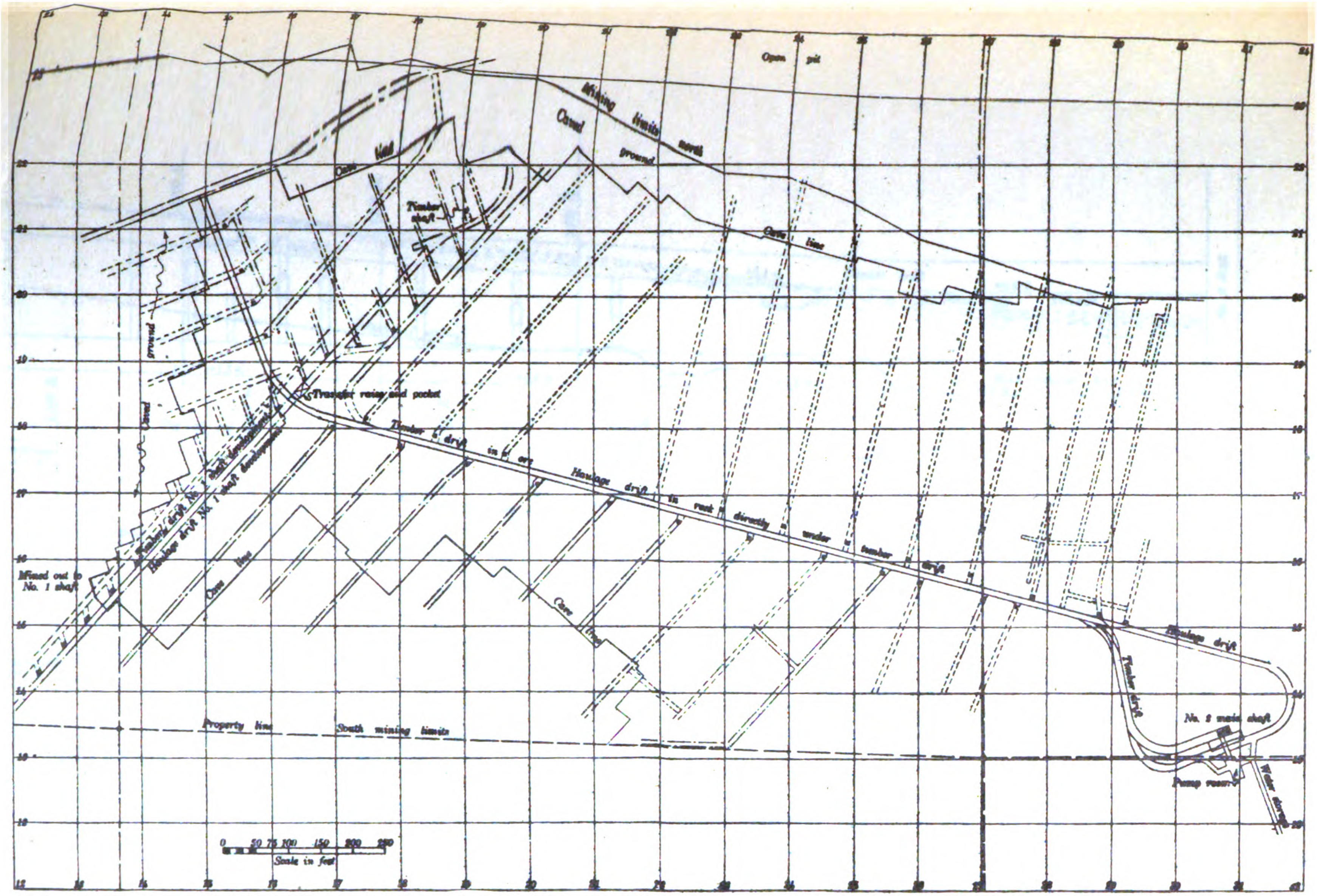


Figure 9 A.-- Plan of development for thin ore body

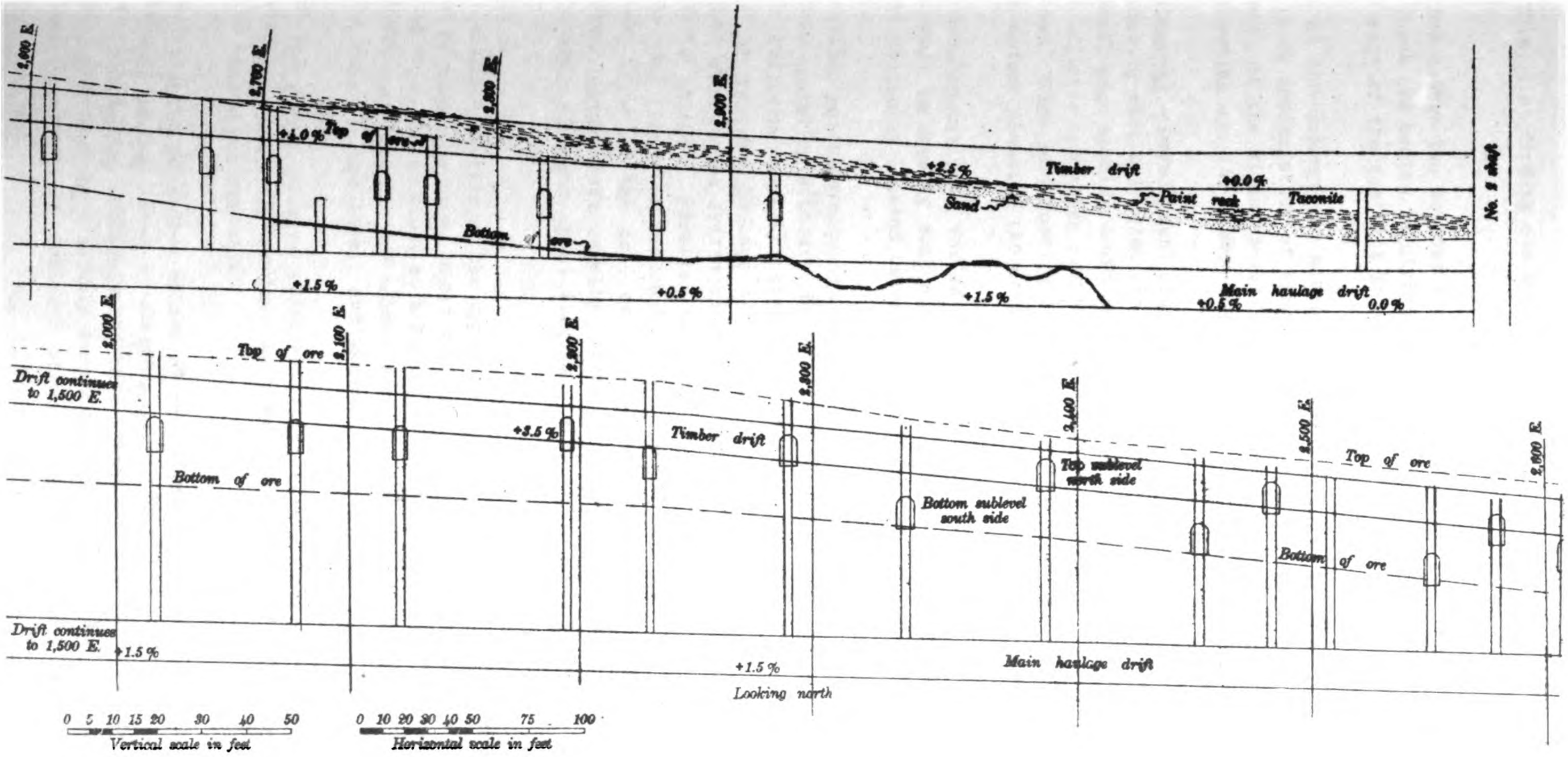


Figure 9 B.- Section of thin ore body showing main haulage level in rock below ore

1. Thin, flat dipping ore bodies only one slice thick - up to about 20 feet (figs. 2, 9A, and 9B).

2. Ore bodies two to four slices thick (fig. 7).
3. Thick ore bodies requiring a series of slices one below the other (fig. 8), as in the central part of the district in the vicinity of Eveleth and Virginia.

Most of the underground mines are in classes 1 and 2. Obviously in the thinner ore bodies no thick accumulation of timber mat occurs, and due to this fact and to the large plan area of most of the mines, sublevel caving is not practicable as the cave comes down quickly upon blasting out the timber support.

Development.- Development plans are based upon previous drill exploration from the surface. Ordinarily vertical holes are drilled at the corners of 300-foot squares. In many cases closer drill-hole spacing would permit better planning of the development and more than pay for itself in later operating economies. Drill holes 150 feet apart would be much better in many instances. Some additional holes are often drilled between those originally drilled 300 feet apart before planning the development.

The development plan varies considerably for different types of ore bodies. In any event the shaft is usually sunk near the low point of the bottom of the ore body or is on one side and centrally located between the ends of the ore body or of the property.

In earlier years development in rock was avoided as much as possible, often at the expense of future operating economy. Main haulage drifts were driven from the shaft and were kept in ore by following closely the bottom contours of the ore on motor haulage grades. Raises were put up from the haulage drifts at intervals of about 50 feet to the top of the ore and connected with timber drifts on each sublevel, starting at the top sub. The sublevel interval was 10 to 14 feet. Parallel tramming drifts (fig. 7) were driven approximately at right angles to the timber drifts on 50-foot centers to match the raises, and toward the margin or "shore line" of the ore, or to the boundary of the property. Where possible, main-level haulage drifts were usually driven in ore under these tramming drifts, and connecting chute raises were put up at frequent intervals to reduce tramming distances on the sublevel (fig. 8).

When tramming drifts on the upper sublevel intersected bottom rock without reaching the shore line or boundary line, short transfer raises were put up (fig. 7B) and the subdrifts continued from these raises at a higher elevation. The ore from these upper subs then had to be transferred through the raises from the upper to the lower sub, trammed to the raises from the main haulage level, and dumped again.

With the advent of more efficient rock drills, rock development is no longer so strictly avoided, and this has resulted in simpler development, better planned to meet the requirements of economical operation.

Figures 9A and 9B show a scheme of development for mining a thin, flat-dipping ore body where the main haulage level is almost entirely in rock. In this illustration the ore is scraped into cars on the sublevels and hand-trammed to chutes. Figure 7 shows a development and mining plan for an ore body averaging three slices in thickness where parallel slicing, scraper-loading into sublevel cars, and hand-tramming to chutes are employed.

Figure 8 shows a development and mining plan for a thick ore body where radial top-slicing with direct scraping to chutes is practiced.

Slicing.- In parallel top slicing (figs. 1, 2, and 7) slicing usually starts on any given sub at the property line or ore margin and retreats therefrom, longwall fashion. The slices are driven at right angles to the tramming drift or timber drift as the case may be, and for this reason the system is sometimes called "right-angle slicing." Sublevel intervals in regular slicing (as distinguished from sublevel caving, which is also sometimes called "slicing," "high slicing" or "caving back") vary from 10 to 14 feet as a rule. Where the ore is only 16 to 20 feet thick, however, it is often taken out with a high slice from floor to capping in one operation. Each slice is started by putting up "opening" sets which are stood at right angles to the drift sets. The drifts are usually driven small, and since the opening sets go up to the capping or mat, as the case may be, the back of the drift opposite the slice has first to be taken down to make room for the open sets. From these opening sets the slice is advanced in one direction to the cave or to the limit of the slice. In some mines the practice is to slice in one direction only from the tramming drift and carry the slice through to the cave or to the next tramming drift (fig. 2). In other instances the slices are driven both ways, but only half-way through the pillar between tramming drifts to meet the slices from adjacent drifts.

Formerly, when hand-loading was employed, it was usual to drive two slices in width before blasting down, thus making one track-laying job serve for loading the ore from two slices. An 8-foot cap and 8-foot (wide) slice were generally used. Sometimes three slices could safely be opened up without taking undue weight.

Since the advent of power scraper loading it has become more or less standard practice to drive slices 10 feet wide and to blast down each slice as it is completed. If a second slice is driven alongside an open slice, much of the ore is blasted into the latter and is difficult to reach with the scraper, especially if, as often is the case, the first slice has become heavy and center props have to be set under the caps.

The slices are usually advanced 5 feet each round and slice timbers are set on 5-foot centers as the slice advances. The slice timbering consists of simple drift sets of round timber, with "joggles" cut on the ends of the caps (fig. 10). These sets are placed and blocked to the sides of the slice, (timber on caved side and ore on the opposite side) and are lagged over and blocked on top. Collar braces of light, round poles are placed between caps at the ends and also between posts of adjacent sets. The lagging is usually of round poles or split round timber, termed "split-lagging."

After blasting and before mucking out the face of the slice, two, three, or more round poles are driven over the cap of the last standing set and under the cap of the next to last set, forepole fashion (fig. 11). These poles are cross-lagged with short boards or pieces of lagging as a protection to the men working at the face and to catch up the overlying mat or capping.

It is usual for a gang of miners (two men) to drill, blast, scrape out, and timber one set of ground (5 feet) per shift.

Slice Timber.- Round, green timber with the bark left on is employed for slice sets. Tamarack makes about the best timber now available. Pine was used to a considerable extent in early years, but is now very scarce and is not obtainable in any quantity. Some

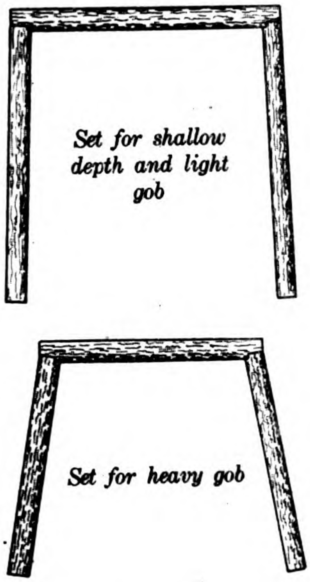


Figure 10.–Slice sets

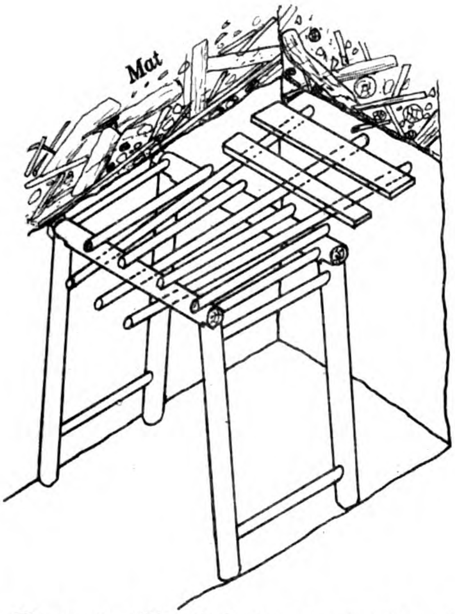
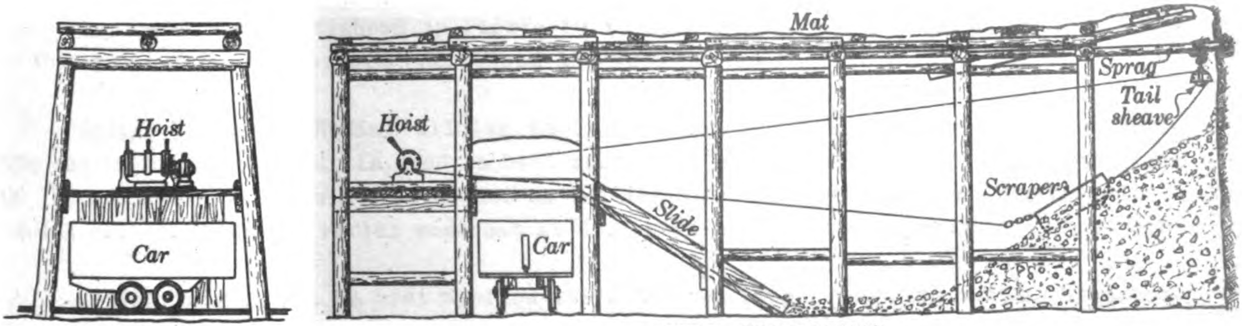


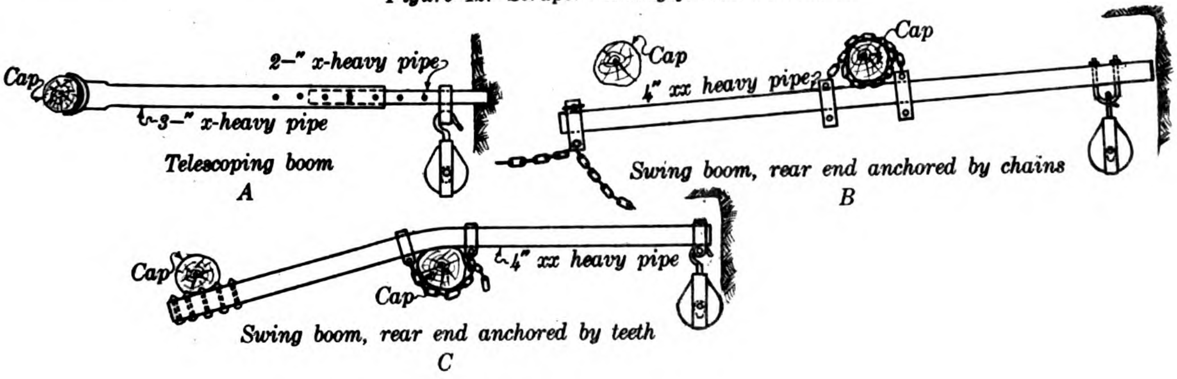
Figure 11.–Slice timbering showing forepoles for catching up overlying mat



REAR ELEVATION

SIDE ELEVATION

Figure 12.–Scraper loading from slice to cars



Telescoping boom
A

Swing boom, rear end anchored by chains
B

Swing boom, rear end anchored by teeth
C

Figure 13.–Types of booms for sheave support hemlock is used and makes good timber. Birch, which is plentiful, does not make desirable slice timber, though some is used.

The timber is purchased on specifications as to size of the "tops" or small ends of the timber. Specifications vary somewhat at the different mines, depending on width and height of slices, pressure developed, and size and price of timber available. Sizes specified by several typical mines are as follows:

Slice timber specifications used by several mines

Mine	Length of cap (width of slice), feet	Diam. of cap timber, inches	Height of standard posts, feet	Diam. of post timber, inches
1	8 or 10	10 - 12	Up to 18	7 - 9
2	10	7 - 9	11 - 12	7 - 9
3	8 to 12	8 - 10	10	8

In the shallower mines where pressures are not heavy the posts are set with little if any batter. In deeper mines where there is heavy pressure and especially where much side pressure develops, the posts are well battered (fig. 10). At a mine on one of the Michigan ranges where there is heavy side pressure, posts are battered 2½ inches to the foot. At some mines specifications call for 9 to 12 inch posts and 12 to 15 inch cap timber.

Caps are framed as shown in Figure 10 to have a full bearing on the post. Sometimes the ends of the cap even extend beyond the tops of the posts.

Radial Slicing.- Radial slicing has come into use with the advent of scraper-loading and is employed mostly in, and is best suited to, mines where the ore is several subs thick. For this reason it is not so common on the Mesabi as in the other iron-ore districts. The radial slicing practice varies somewhat at different mines but in principle is the same.

Radial slicing can be best applied where the ore body is deep so that it is possible to arrange haulage drifts with chute raises therefrom spaced at such intervals that the ore may be scraped to them directly from the face without exceeding the economical scraping distance, and where this can be accomplished without an excessive amount of development in rock.

Whereas in parallel slicing the ore is commonly loaded into cars and then trammed to chutes, in radial slicing the ore is all scraped directly into chutes without any intermediate handling (figs. 5, 8, and 15). The radial slice was of course designed to permit scraping the ore from a considerable area directly into chutes without dragging the ore around sharp turns. As previously stated, right-angle turns and sharp bends can be negotiated by the scraper, generally with the use of deflecting sheaves for the ropes and rollers or boards nailed to the bottoms of the posts on the corners to ease the scraper around them and prevent its catching on the timber. Small scrapers (36 inch box-type) are being used at one of the mines visited, and are pulled around right-angle turns without the use of rollers or boards and seem to work very successfully. Larger scrapers would probably not work so well.

By close spacing of raises on the sublevels, parallel slicing may also be used for direct scraping to chutes. Where this method is employed the tops of the chutes are usually about 15 to 18 feet or even 35 feet apart on the sublevel, the closer spacing being sometimes accomplished by driving branch raises from the main raises starting on the next sub below. One slice directly opposite the raise and one slice on each side thereof, or three slices in all are thus tributary to each raise.

Figure 8 shows the general plan of working at a Mesabi Range mine where radial slicing is employed. The sublevel interval is 12 feet. A longitudinal timber drift "A" is driven, from which tramming drifts "B" (which in this case are not used for tramming but merely for development, ventilation, and access to the slices) are driven at right angles thereto on 110-foot centers and connect a series of raises "R" "R" "R" put up from the haulage level drifts. Slicing starts at the raises nearest the cave, property line, or mining limit. The first slice is generally driven along the cave if the cave comes to the side of the chute and succeeding slices fan out therefrom. If the cave does not come up to the raise a slice is started toward the cave and normal to the side of the chute raise and is carried to the cave.

After the first slice is driven, the second slice is started by propping the cap of the first set beyond the opening set, removing the post on the side next the radial slice and blasting out a triangular cut (fig. 5D). A radial slice set is placed as shown. Sometimes the second cut can be taken without disturbing the next set of the first slice. In other instances it is necessary to prop the cap and remove the post as for the first cut. The standard slice set at this mine has a 10-foot post and 8-foot cap. The first radial slice set usually requires a shorter cap, the second set a standard 8-foot cap, and when the end of the slice is reached caps 12 or even 13 feet in length are sometimes required. The length of cap which can be used will depend on the nature of the ground, gob, and pressure.

At other mines standard caps are employed for all sets. In some mines instead of starting the first radial slice close to the chute, a triangular slice is taken at the inner end of the first slice (fig. 5B).

The main objection to radial slicing would seem to be the difficulty of standardizing the cuts and the timbering. While the placing of timber may not be much more difficult than for parallel slicing, standardization of work, timber, and of the slicing cycle which is possible with parallel slicing is an advantage possessed by that method which is not possible with radial slicing. Also, in radial slicing where different lengths of caps are used, close supervision is necessary to prevent the cutting up and wasting of timber.

Handling and Loading.- As previously stated, the ore from the slices was formerly shoveled by hand into sublevel cars and trammed to the main level chutes.

To-day practically all the ore both from development and slicing is handled by power scrapers which either load into sublevel cars or scrape directly into chutes. In the first instance a short timber slide is constructed, the loaded scraper is pulled up the slide and discharges the ore into a car placed underneath. The scraper hoist is usually placed in line with and on the opposite side of the drift from the slice (fig. 12), but sometimes it is put on staging back in the drift, in which case sheaves must be employed to guide the ropes around the turn.

When scraping direct to chutes no special preparation of the place is required. In direct scraping, however, radial or angle slicing is often employed instead of parallel or right-angle slicing to avoid pulling the scraper around sharp corners. This can be and is done by some operators by using an open sheave or snatch block to divert the pull from one direction to the other. This requires the man at the face to follow the loaded scraper out to the turn and throw the pull-rope off the sheave when the loaded scraper reaches that point.

The earliest scraper equipment consisted of the ordinary two-handled surface scraper or "slusher" drawn by a small, single-drum air tugger. The scraper was pulled back to the face by hand and guided into the muck pile by the man at the face, the tugger pulling it into the dirt and out to the car or raise. This was an improvement on hand shovelling but was inefficient for distances greater than about 25 or 30 feet. The small slusher is still employed in some mines for clean-up work.

Present scraping equipment consists of 36 to 48 inch (or larger) scrapers of the box or hoe type, operated by 6-1/2 to 25 horsepower double-drum electric hoists. The trend has been toward larger equipment, and 42 to 48 inch scrapers and 10 to 15-horsepower hoists are the standards for new equipment. At many mines the operators are now buying nothing smaller than 15-horsepower hoists. For top-slice mining it is probable that the economical limit in size has been reached, since sufficient ore per shift is not handled in each place to warrant larger equipment. Furthermore, larger equipment would be hard to move through raises, handle, and install, and larger scrapers would not pass as easily between timbers.

In top slicing, the miners work in pairs on contract. Since two shifts are normally worked, there are four miners on a contract. Each contract is usually assigned the slicing and drifting tributary to one chute and may have one, two, or occasionally three faces in which to work. The contractors do their own timbering, drilling, blasting, scraping, and tramming at a set price per car of ore. Each contract is furnished with all equipment, including scraper, hoist, rope, sheaves, drills and steel, etc.

For pulling the empty scraper to the breast, a tail sheave is secured at the face, usually to a boom, which permits cleaning the face out well after each blast. Often the boom consists merely of a wooden sprag or pole with one end against the last cap and the other headed in a hitch cut in the face near the top of the slice (fig. 12). Another type of boom is the telescoping boom made of heavy pipe (fig. 13A). A third type is of extra heavy pipe which is suspended under the last cap with a chain and having two chains on the rear end to secure the boom in any desired swing position (fig. 13B). Matson has discussed and illustrated several other types of booms.[3] Sometimes in harder ores an eyebolt inserted and wedged in a drill hole in the breast secures the tail sheave.

With the trend toward larger scraping equipment has come the use of longer scraping distances with an attendant smaller amount of development work required. At most every mine visited longer slices were either contemplated for new levels or the statement was made that if it were to be done over again plans would be made for longer slices. With the present scraping equipment the length of slice is governed to a considerable extent by the length that will stand up well, which depends in turn upon the ground and the gob. It may also be governed by the number of working places needed to furnish the required output rather than by the capacity of the equipment.

At one mine the main and sublevel drifts are 50 feet apart, and the raises 25 feet apart along these drifts. On the new levels it is planned to drive the tramming drifts on

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3 - Matson, Robert C., Scraping Practice in the Michigan Iron Mines of the Lake Superior District: Proc. Lake Superior Mining Inst., vol. 26, 1928, pp. 224-230.

110-foot centers which will give 55 feet scraping length on each side. At another mine where the tramming drifts are 50 feet apart and where slices are driven on one side only, this spacing was necessary to provide the required number of working places.

The operators of a single-sub mine where the drifts are 75 feet apart stated that if they were to develop the mine over again they would make the interval 100 feet or more.

The slices are illuminated by electric lights on long, heavily insulated extension cords so that they may be placed in the most advantageous positions.

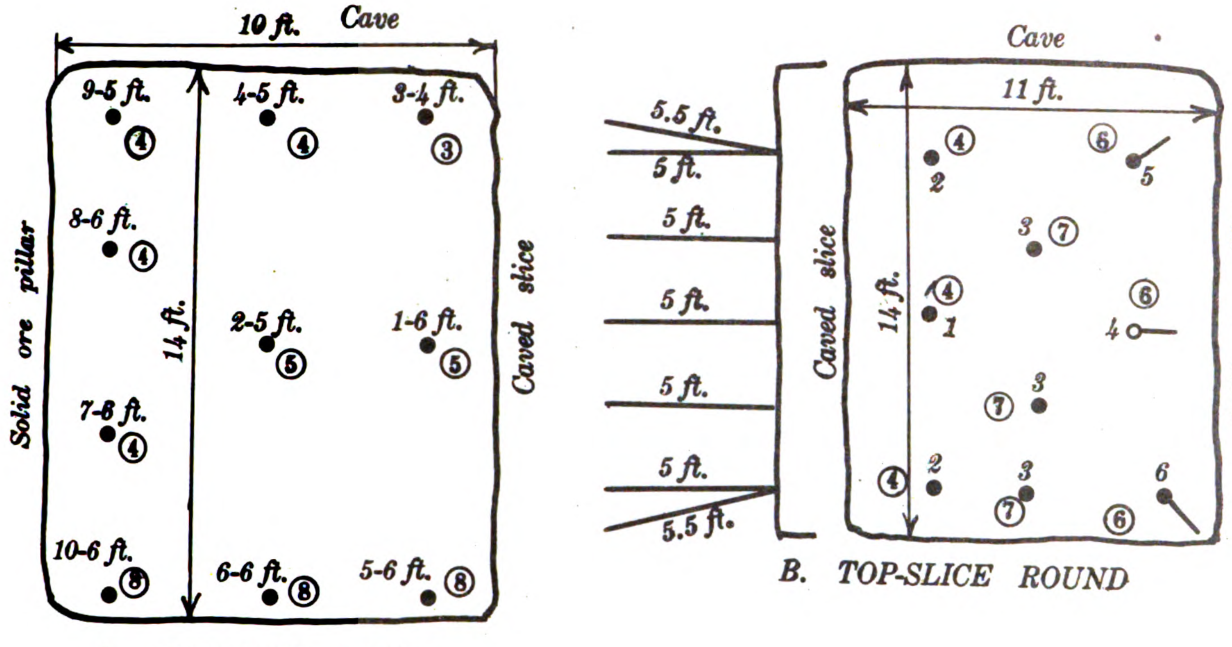
Blasting Down.- When a slice is completed, the side next to the solid ore is usually boarded up or covered with wire fencing, and the bottom is covered down. Practice varies at different mines with conditions or the preferences of the operator. On the Mesabi Range there is often a good deal of sand in the gob; where this case is so it may be necessary to cover the bottom and sometimes the sides with boards to prevent contamination of the ore in the next slice or in the next sub below. When there is no ore below, as in single-sub mines or when the bottom slice of the ore body has been reached, it is obviously unnecessary to cover the bottom. Some mines use wire fencing on the sides and boards on the bottom of the slice. Others use the wire on both sides and bottom. When wire fencing is used on the bottom, it is customary first to lay poles longitudinally and then to cover them with the fencing, which is secured to the poles with fence staples. The poles are generally spaced about 12 to 24 inches apart and are long enough to span two sets; sometimes they are 16 feet long. In some places where there is sand in the gob, poles are laid first and then covered with both boards and wire fencing.

In former years the boards employed were 1-inch pine "mining boards," a grade of board below the poorest of the ordinary commercial grades. To-day the mining boards are usually of hard wood and are only three-eighths to one-half inch thick.

All the mines where wire fencing is employed for side or bottom cover use the same material. It is a low-priced, galvanized-wire, diamond-mesh, "station ground fencing" in 42 inch wide rolls, 10 rods, in length costing about $12.50 to $13.50 per 1,000 square feet. The mesh is strengthened by 11 longitudinal strands of double wire twisted together. The material cost is said to be about the same as that for boards to cover an equal area, but the cost of handling and placing is very much less for the wire than for the boards. In top slicing the cost of handling timber is an important item, which is considerably increased where mining boards have to be handled and transported. At one mine using sublevel caving it was said that wire cost 0.7 cents per ton of ore mined and boards about 4 cents per ton, the difference being largely in cost of handling and placing.

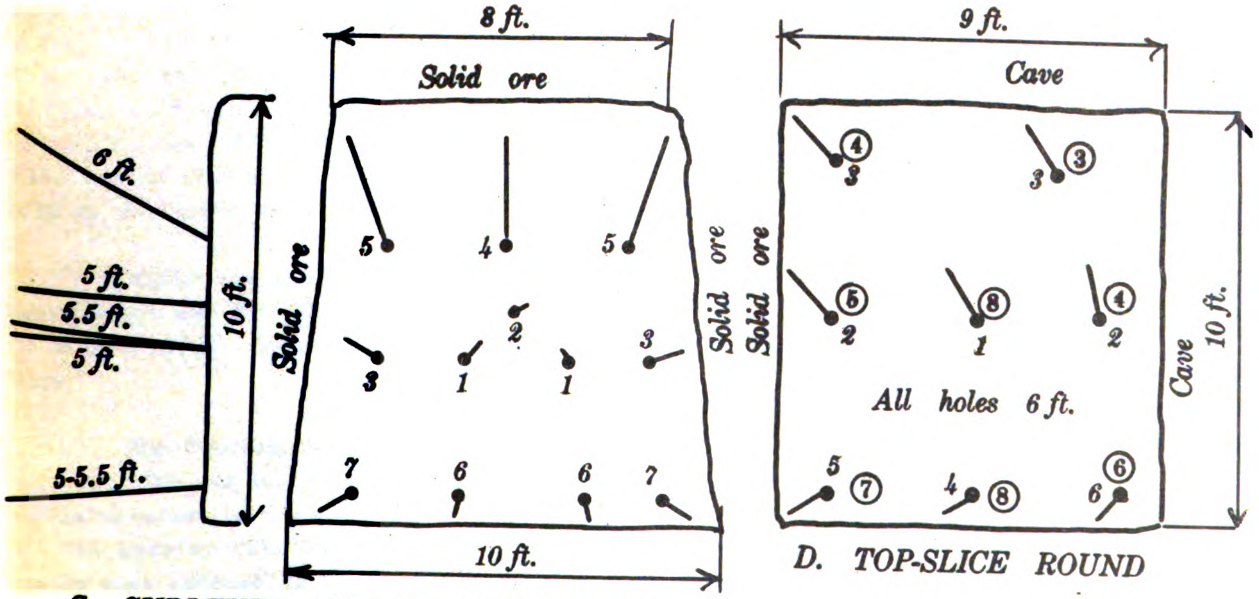
In some deeper mines where there is a thick timber mat, it is unnecessary to use any cover on the side of the slice, as when it is blasted down, the gob is practically all wood.

When the slice is covered down, whatever the method employed, the entrance is propped and boarded up, the posts next to the cave are drilled with an auger, pieces of sticks of powder with fuse and caps are inserted in the holes, and the timber is blasted down. It is usually possible to start the next slice alongside the blasted slice the following shift or next day. Sometimes if the cave is not tight and is still "working," a short lapse of time is desirable before starting the next slice.



A. TOP-SLICE ROUND

B. TOP-SLICE ROUND



D. TOP-SLICE ROUND

C. SUBLEVEL CAVING SLICE ROUND

Figure 14. — Types of slice rounds. Numbers in circles indicate number of sticks of dynamite; other numbers indicate order of firing

Slicing may proceed on the next sub below as soon as the cave is quiet and well settled. Slicing may thus proceed on several sublevels at the same time, but the slicing on any given sub must always lag behind that on the sub above by a few slices so that the mining is always under a settled mat.

Drilling and Blasting.- The Mesabi Range ores are soft hematite and limonite ores and are drilled with auger steel. Up to about 1916 most of the drilling in ore was done with hand augers. To-day hand augers are sometimes employed for drilling holes in treacherous slabs of ground where the vibration produced by drilling with hammer drills might loosen and jar down the slab. Practically all drilling in ore, however, is now done with light jackhammer drills equipped with special rotation for use with auger steel. The soft ores drill easily and are easily broken. In slices it is usually unnecessary to drill any regular cut holes, but all the holes except the lifters are drilled at an upward angle. Figure 14 shows typical drill rounds in slices. Figure 14C, is a round used in sublevel caving slices.

For rock development heavy or medium weight Leyner-type drifters are employed.

In slicing, the ground is broken with 35 or 40 per cent low-freezing gelatin dynamite or "Red Cross" dynamite and the powder consumption averages around 0.4 pounds per ton of ore broken. For rock development 50 or 60 per cent strength explosive is commonly employed. Table 7 gives the explosive consumption at a number of mines in the Lake Superior district where the top slicing or sublevel caving methods are employed.

In top slicing, care must be taken to avoid blasting out the timber, as the last set is very close to the face of the slice. In hard, tough ground the difficulty is obviously greater than in soft ore. Before blasting, collar braces are put in between the caps of the last two sets, one on each side; between the posts of the last two sets just below the caps, and braces are inserted between the posts near the bottom. Sometimes the cap is reinforced by tie braces to the legs. This usually prevents knocking down the timber, but the timber may be broken if the side and back holes are too heavily loaded or if the first holes to go do not break well to form an opening for the outside holes to break to.

Since top slicing is the universal method of underground mining employed on the Mesabi Range and has been for many years and is representative of top-slicing practice in the Lake Superior region, the main discussion of the method has been given under "Mesabi Range."

Top-slicing is also used on some of the other ranges, but other methods are also employed. The ore bodies on these other ranges are quite different in occurrence and physical characteristics from the Mesabi ore bodies and are often narrower and usually much deeper. The more or less standardized practice of the Mesabi, therefore, is varied in certain details when applied to the mining of these ores. These variations will be discussed in the following pages. At this point, however, it may be emphasized that one of the principal differences is in the development practice. In the shallower Mesabi ore bodies it is usually feasible to carry development considerably in advance of ore extraction and it is often unnecessary to timber development headings. In the deeper mines such as those of the other ranges, however, development is carried in advance of mining only to the minimum extent required to maintain output, since otherwise maintenance expense would be prohibitive. The development headings usually have to be timbered as they are driven.

2. Cuyuna Range

On the Cuyuna Range in Minnesota the ore bodies occur in the form of lenses in intensely folded slates, schists, and cherty formation. Most of the ore is fairly soft, but hard ores occur also. As on the Mesabi Range, some of the ore bodies are wide and at shallow depth, and are minable by open-pit methods. The district is covered by a thick overburden of glacial drift, which is water-bearing.

Narrow lenses of ore dipping at rather steep angles are common, and these are mined by underground methods, both top-slicing and sublevel caving being employed.

At one mine visited the thickness of the ore varies from a few feet to a maximum of 50 or 75 feet; the immediate hanging wall is a soft paint rock which is heavy and sloughs readily, especially where it is wet, as it often is. The dip varies from 55 to 75°, averaging about 65°. The ore does not occur uniformly along the strike, but consists of several lenses or bulges more or less connected by narrow seams of ore.

Main levels are driven about 150 feet apart vertically and consist of a short crosscut from a vertical shaft and a single longitudinal drift along the footwall (fig. 15). Two-compartment cribbed raises are put up along the footwall at intervals of about 50 feet, though this varies, depending upon the location and lengths of the ore lenses.

Timber drifts are driven connecting these raises along the footwall and are about 80 feet apart on the dip. Connecting drifts are not driven on the intermediate subs between these timber tramming levels, but tuggers are employed to hoist timber up to them from the timber drifts. Timber and men are handled through a timber shaft at some distance from the ore-hoisting shaft.

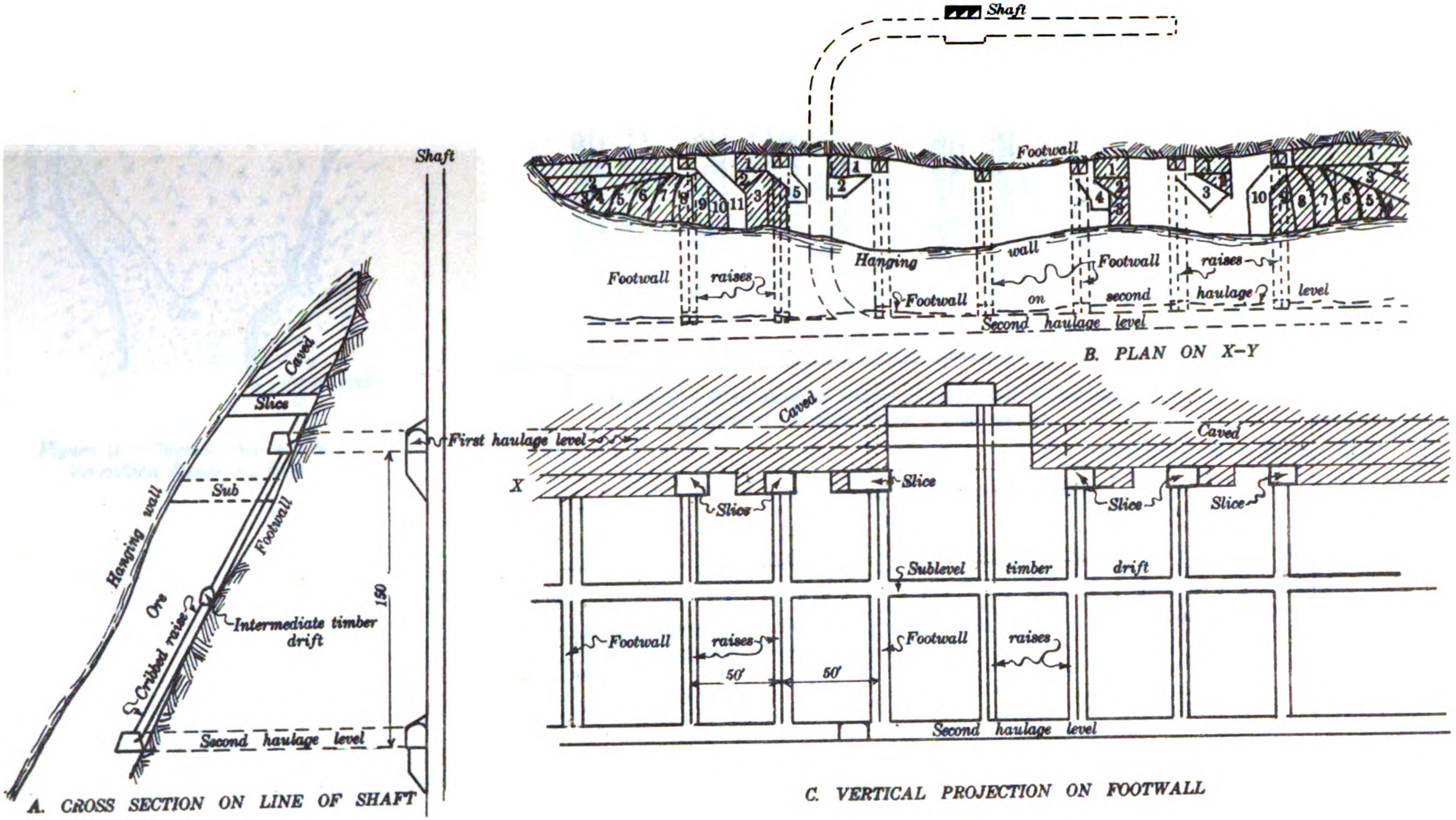
The radial top-slicing system is employed at this mine, the sublevel interval being 11 feet. Radial slicing is started from the raise on any given sublevel, and the first slice is usually driven along the footwall. Succeeding slices are swung around from the footwall on one side of the raise to the footwall on the other side, though this practice is sometimes varied to meet local conditions. As the heavy hanging wall is approached, the slices are swung so as to meet it at an angle of 90° (the last caps parallel to the strike). Contamination of the ore by hanging-wall paint rock is carefully avoided.

A full-width slice is 12 feet, but the slice narrows where it branches off from a preceding slice or from the raise. Some slices are as long as 100 feet, but usually less, the length depending upon the spacing of the raises and width of the ore.

After a mat has been started no boards or wire fencing are used on the sides of the slices but the bottom of each slice is carefully covered with poles across which are laid ½-inch hardwood mining boards. No wire fencing is used at this property.

Specifications for timber are as follows:

	Top size, inches
Posts	9 to 12
Caps	12 to 15
Lagging	5 to 7
Poles	3 to 5



A. CROSS SECTION ON LINE OF SHAFT

B. PLAN ON X–Y

C. VERTICAL PROJECTION ON FOOTWALL

Figure 15.— Scheme of development and mining, Cuyuna Range

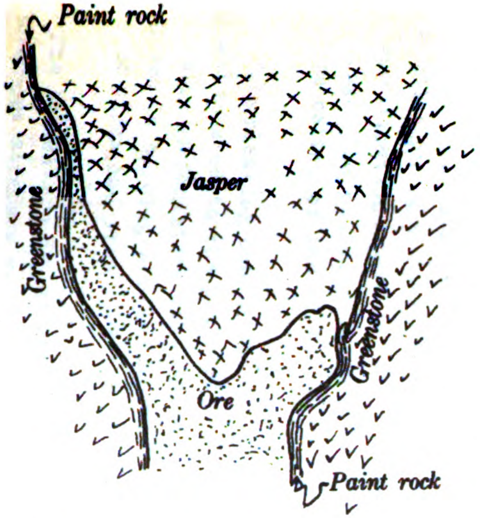


Figure 16.—Typical cross section, Vermillion Range ore body

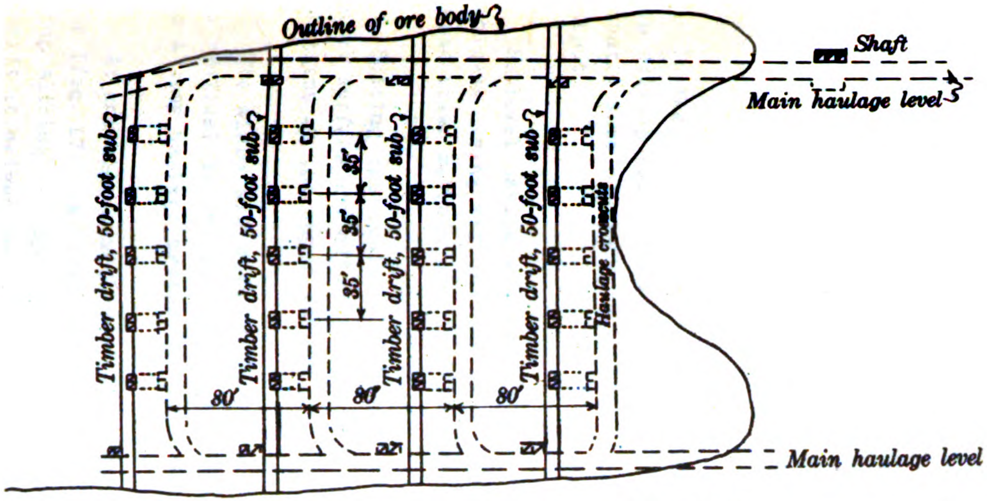

Outline of ore body
Shaft
Main haulage level
Timber drift, 50-foot sub
Timber drift, 50-foot sub
Timber drift, 50-foot sub
Timber drift, 50-foot sub
35'
35'
35'
80'
80'
80'
Haulage crosscuts
Main haulage level

Figure 17.—Plan showing scheme of main and 50-foot sub development in wide ore for radial slicing

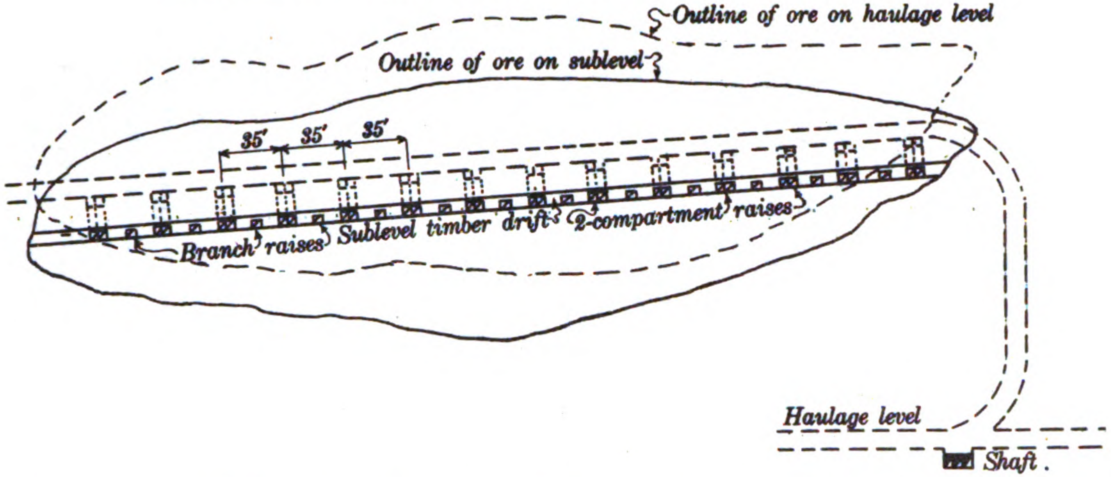


Figure 18.—Vermillion Range development plan in narrow ore, for parallel top slicing and sublevel caving; 12.5-foot interval for top slicing, 20-foot interval for sublevel caving

Scraping is done by means of a 34 inch wide box-type scraper with rounded sides and with a 200-pound lead weight on the back. The rounded sides are said to be an advantage in getting around the timbers.

3. Vermilion Range - Minnesota

At Ely, Minn., the ore occurs in a deep trough between greenstone walls and under a capping of jasper (fig. 16). The immediate wall rock is usually a thin layer of paint rock. The ore bodies are irregular in outline and vary in width up to 300 or 400 feet. The ore varies in character from soft hematite to hard specular hematite and is high in iron content.

In the earlier years of the mines a chute-caving method of mining was employed. Later top slicing was introduced to secure higher recovery and less dilution of the ore. More recently some of the mines have introduced sublevel caving for mining part or all of their output.

Sublevel caving will be discussed in some detail under "Gogebic Range." On this range sublevel caving may be said to be almost as standard as is top slicing on the Mesabi, though some other methods are employed on the Gogebic.

Slicing and sublevel caving operations are now being carried on at considerable depth below surface and often under a mat accumulated from several hundred feet of top-slicing operations on the upper levels.

The mines are developed by shafts from which main haulage levels are driven at 100-foot vertical intervals. In the widest ore bodies the main levels are sometimes laid out with a loop haulage system having cross drifts 50 to 80 feet apart.

At one mine a new level is being developed with cross drifts 80 feet apart center to center (fig. 17). At this mine raises are put up from the cross drifts on 35-foot centers Radial top slicing is employed with a sublevel interval or slice height of 12-1/2 feet. A timber drift is driven on the sub 50 feet above the haulage level (halfway between the main haulage levels), but no timber drifts are driven on the other subs, all timber being hoisted up to them with tugger hoists.

The mat consists of timber accumulated from 400 feet of top slicing on the upper levels, and although very heavy it serves to prevent contamination of the ore with rock. The timber specifications call for 8 to 10 inch round timber for both posts and caps. Caps are 8 feet long. The posts, which are 10 feet long, are battered to give a slice width of 10 feet at the bottom of the slice.

Before blasting down a slice, round poles are placed on the bottom and wire fencing is laid on and secured to the poles with fence staples. As the mat is practically all timber with practically no admixture of capping, the side of the slice does not have to be covered at all. Often in driving a slice along the cave, the mat looks like a solid pile of cord wood it is so clean and free from waste.

The broken ore is scraped from the slice directly into the chutes by means of 48-inch, hoe-type scrapers weighing about 750 pounds and operated by double-drum, 15-horsepower, electric tugger hoists. The scrapers are constructed with teeth on one side and a manganese steel edge on the other. There are eight manganese steel teeth. In spite of the thick accumulation of mat at depths of about 1,200 to 1,400 feet, good ventilation is maintained and very warm places are rare.

Another mine where the ore trough dips at an angle of about 70° is developed by a vertical shaft in the footwall, from which haulage levels are driven at 100-foot intervals. The ore averages 100 to 125 feet wide in one section of the mine and is as much as 300 feet wide in another section. The ore varies from soft to very hard specular hematite. Main-level development consists of a crosscut to the ore body on each level and a longitudinal drift down the center of the ore body (fig. 18).

From this drift raises are put up on 35-foot centers and are driven at an inclination of 70°. Parallel top slicing is used in some sections of the mine and sublevel caving in others. The sublevel interval is 12½ feet for top-slicing and 20 feet for sublevel caving The line of raises are connected with a timber drift on each sublevel. Before starting the slices, which are driven each way (to the foot and to the hanging) on any given sub, inclined branch raises are driven from a point 20 feet, below to split the distance between the main raises on the slicing level. This permits scraping directly to the chute raises without resorting to radial slicing and without scraping around sharp corners.

The slices are driven 10 feet wide, using 10-foot posts and 10-foot caps both for top slicing and sublevel caving. Mining is conducted under a heavy accumulation of slice timber as in the mine previously described. Sets are spaced 5 to 6 and even 7 feet apart, depending upon the way the ground stands. The posts are battered. Slices average about 60 feet in length, although where the ore is wide they are longer. With 15-horsepower, double-drum, electric tuggers and 48-inch, hoe-type scrapers, the longer slices do not affect the scraping efficiency noticeably. With the smaller tuggers formerly employed and still used to some extent 60 feet was the economic limit of length.

In top slicing, each 10-foot slice is blasted separately. Because of the good timber mat which is established, no covering is used on the side of the slice. The floor of 2-inch plank which is laid on the bottom of the slice as it is advanced to form a smooth bottom for the scraper is left when blasting down the slice.

At this property sublevel caving is replacing top slicing to a large extent. The remarkably good timber mat hangs up well while the ore is being caved back on the retreat and very clean mining is possible. Sublevel caving is discussed at greater length under "Gogebic Range." At the mine here discussed, the practice varies depending upon whether the mining is in a hard or a soft ore section. In either case the sublevel interval is 20 feet. In soft ore the slice is driven from each raise to the foot or to the hanging wall, leaving a thin pillar between adjoining slices to be mined on the retreat. One-half or about 4 feet of the pillar is mined from each slice. In hard ore, however, each slice is driven along the cave of the preceeding slice to obtain the better and cheaper breaking offered by the free face along the cave. This is the only important variation from the ordinary Gogebic Range practice. In caving back, the usual practice is employed; during this operation it is usual to obtain 40 to 60 tons per man-shift, and larger tonnages are not uncommon.

In the hard ore heavy Leyner-type drill machines and regular hollow steel with cross bits are used, whereas in the soft ores light hammer drills having a specially strong rotation are employed with auger steel.

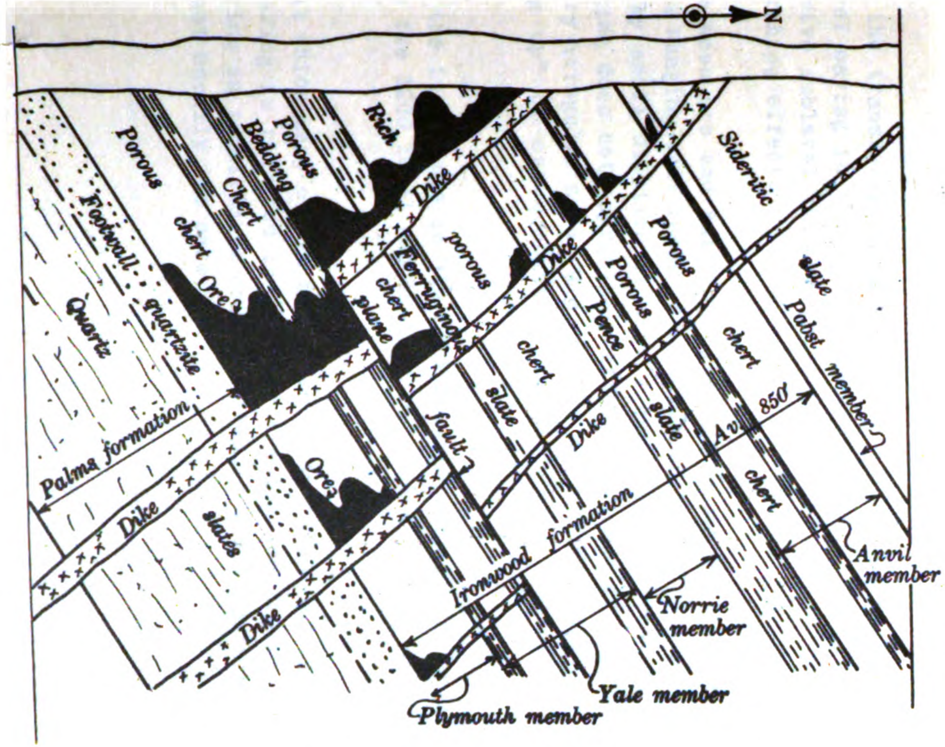


Figure 19. – Generalized section of Gogebic Range

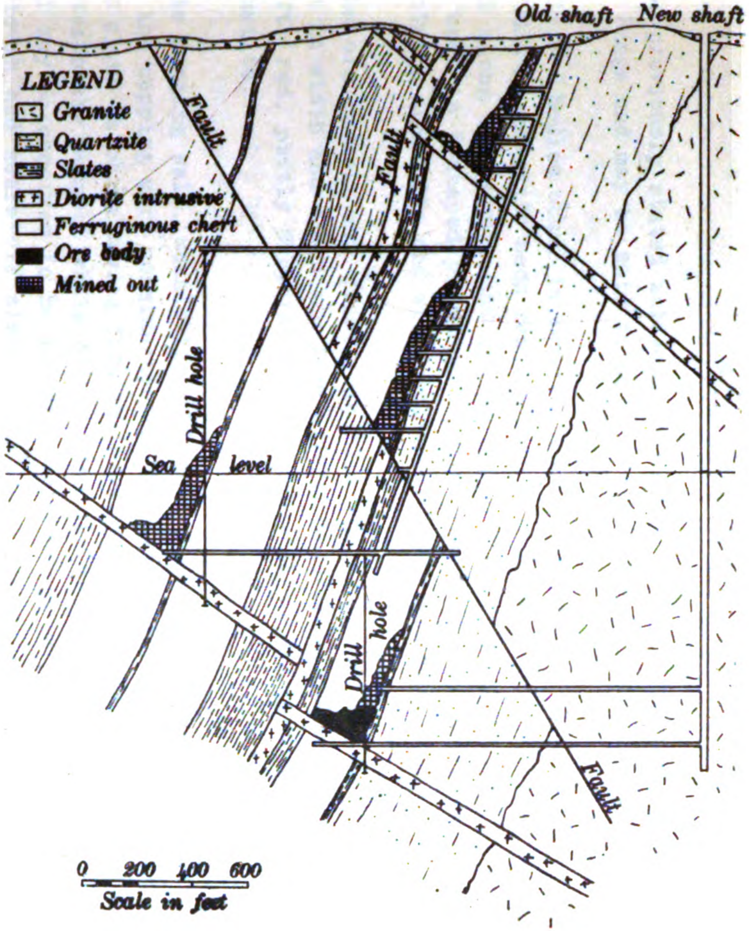


Figure 20. – Typical cross section of a Gogebic Range mine showing scheme of development

4. Gogebic Range

As previously stated sublevel caving is the principal underground method used on the Gogebic Range and may be said to be characteristic of that range.

The ore bodies occur in several productive horizons in a series of steeply dipping (55 to 70°) cherty and slaty beds resting on a quartzite footwall. These formations are very regular both along the strike and on the dip. They typically occur as concentrations of ferruginous beds in V-shaped pitching troughs formed by the intersection of igneous dikes with the footwall quartzite and with impervious slaty members (fig. 19).

The ore bodies vary greatly in size and shape and may be a few feet to several hundred feet in width and depth and from several hundred to several thousand feet long. The ores are ft, red, partly dehydrated hematites with subordinate amounts of hard "blue" or specular hematite.

The hanging wall, consisting of bands of partly leached cherty iron formation and slates, and the capping vary considerably in hardness and tenacity, but as a rule they break in blocks or slabs which in caving form an interlocking gob that arches over so as to require only light temporary support while driving and caving back the slices. In some places the hanging wall may be observed to be intact over openings of considerable size. In others it starts to slough and scale off almost as soon as it is exposed, even over the face of an ordinary slice drift. In some places where it is quite wet the hanging wall will cave down suddenly in large slabs with very little warning, which is a condition not so well suited to sublevel caving.

The V-shape of the transverse section possessed by most of the ore bodies is especially suited to sublevel caving in that it delays the caving of the gob by reason of the fact that on each successive sublevel the ore is narrower than on the sub above, which assists in producing the arching effect.

The boundary between ore and walls is often sharp and well defined, but is sometimes very irregular. The hanging-wall rocks in some places are quite high in iron, however, and in such localities any small dilution of ore by hanging-wall rock occurring in caving operations under the hanging does not appreciably affect the grade of the ore. The outlines of the ore bodies are very irregular as a rule, due to cross-fault zones of fracturing and to the eratic "following up" of ore concentrations above the impervious bottoms of the trough.

The deepest of the iron mines in the Lake Superior region are on this range. One mine is now developing on the 3200 level and another on the 2600 level, and others are below 2000 feet in depth.

At the depths at which many of the mines are being worked the pressures are heavy, and as a rule heavy timbering is required in all drifts which are in ore. In some places, however, even more timbering is required in drifts driven in the immediate footwall than in the ore, though this is not usually the case.

In some localities the beds are displaced and badly broken by faults running in various directions.[4]

Development (fig. 20).- Inclined or vertical shafts are sunk in the footwall, and crosscuts are driven to the ore bodies at intervals varying from 110 feet to as much as 300 feet measured on the dip. Inclined shafts were more commonly sunk in the earlier years, but the newer shafts are usually made vertical. At one mine it is planned to standardize with level intervals of 165 feet along the dip or about 150 feet vertical. At another mine a 125-foot (vertical) level interval has been adopted. At yet another mine the standard level interval is 132 feet and at another is 200 feet.

When the crosscut reaches the ore body, a longitudinal drift is run in ore near or on the footwall. In some mines where there are both foot and hanging wall ore bodies, longitudinal drifts are driven on or in the footwall of each. The exact position of the longitudinal drifts depends on the width of the ore body; on the relative cost of maintaining haulage drifts in ore and wall rocks, respectively, and at different ore horizons; and on whether cross drifts or longitudinal drifts stand up better.

At one mine visited, the longitudinal drift was driven east from the crosscut in the footwall rock and west in ore near the footwall. In some instances the drift is driven in the center of the ore body, and in still others there is a footwall drift and one or more parallel drifts where the ore is very wide. Figure 21 shows typical development plans for different widths of ore.

Usually, however, wide ore bodies are developed by means of a longitudinal haulage drift near the footwall with transverse haulage drifts therefrom at intervals of 100 to 150 feet (fig. 21A). The transverse drifts will usually stand better than the longitudinal drifts and require less retimbering.

The sublevels are developed by a series of raises from the main haulage drifts. Where the main haulage level is developed by one or more longitudinal drifts, the line or lines of raises will parallel the strike (figs. 21B and 21C). The raises are put up at an angle of about 65 to 70° (paralleling the footwall); in this case the slices are driven from foot to hanging wall, (fig. 21C) or if there is more than one longitudinal drift, slices are driven from each line of raises half way through the pillar between them (fig. 21B). Where the ore has been blocked out by a series of transverse haulage drifts on the main level, the raises are put up from the transverse drifts (fig. 21A) and are sometimes vertical but more often are at an angle of 65 to 70° at right angles to the drift; in this case there is a series of raise lines running across the ore body, and the slices are driven parallel with the strike, usually in both directions from the raises to take half the pillar on each side.

The raises are generally two-compartment cribbed raises. One compartment is lined with plank for an ore pass and the other contains the ladders, a timber slide, compressed-air line, and sometimes a flexible ventilating pipe.

The raises are usually spaced 18 to 40 or 50 feet apart and even as far apart as 200 feet in very narrow ore bodies.[5] In all but the very narrow ore bodies the raise inter-

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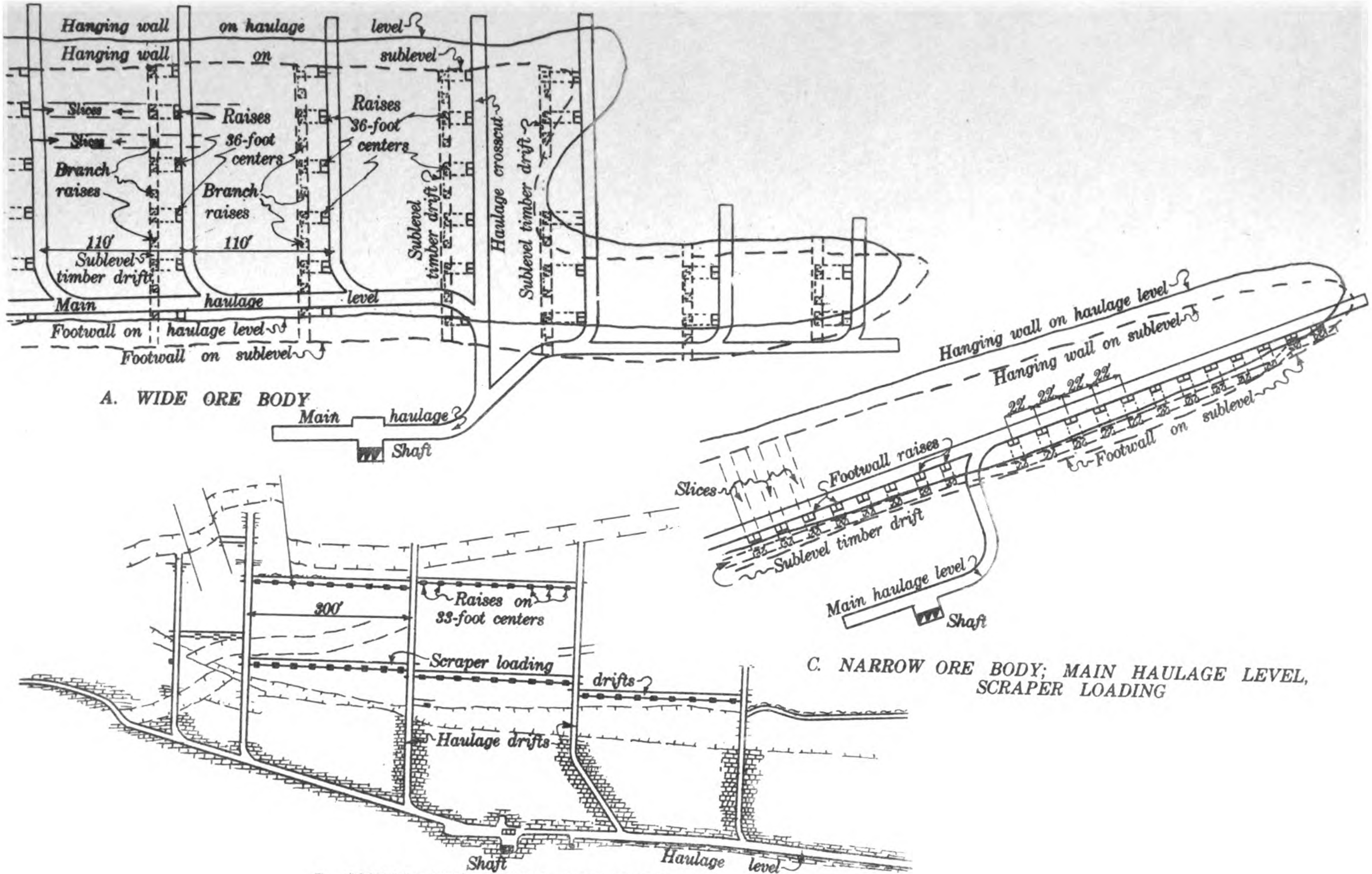
[4] - Schaus, O. M., Method and Cost of Mining Hematite at the Eureka-Asteroid Mine on the Gogebic Range, Gogebic County, Mich.: Bureau of Mines Information Circular 6348, 1930, p. 2.

[5] - Schaus, O. M., Information Circular 6348, cited.

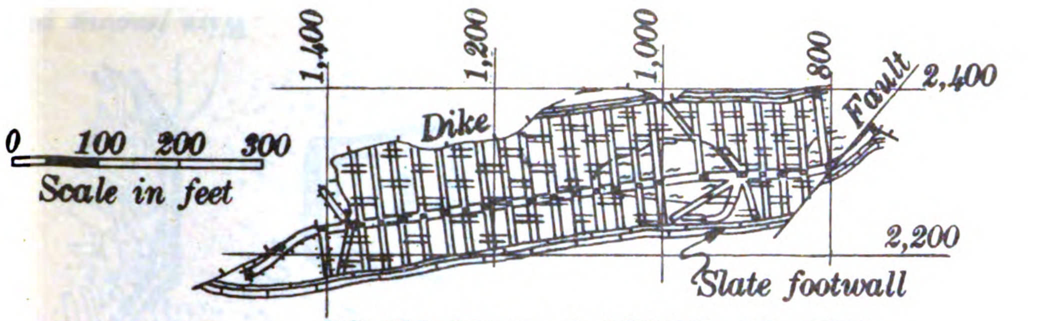


A. WIDE ORE BODY

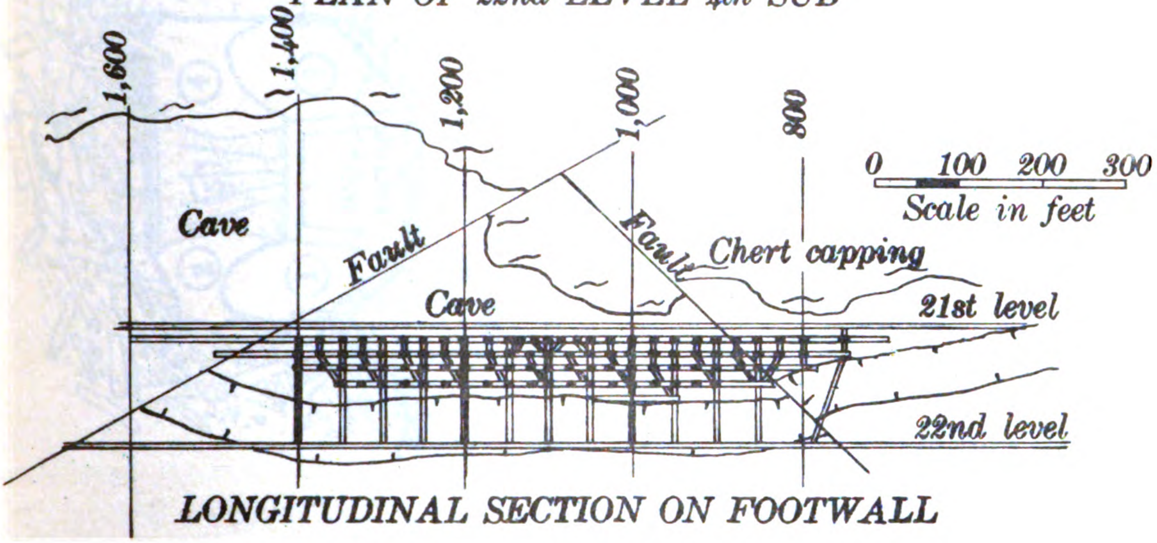
B. MODERATELY WIDE ORE BODY

C. NARROW ORE BODY; MAIN HAULAGE LEVEL, SCRAPER LOADING

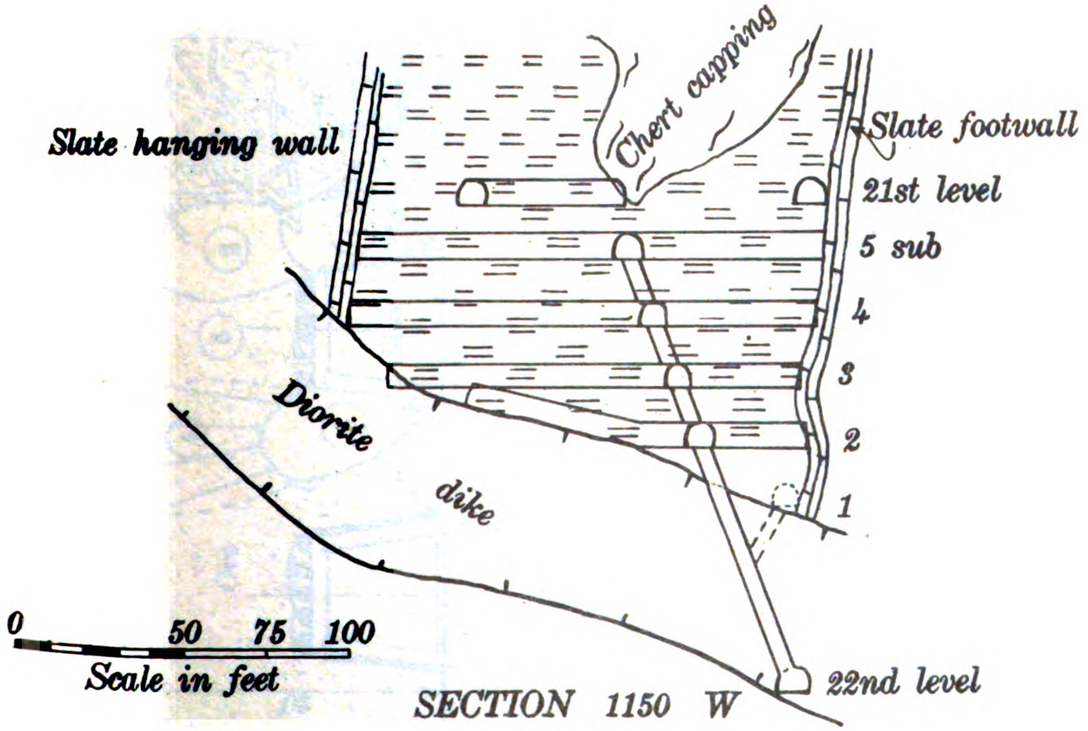
Figure 21.—Development plans for sublevel caving, Gogebic Range



PLAN OF 22nd LEVEL 4th SUB

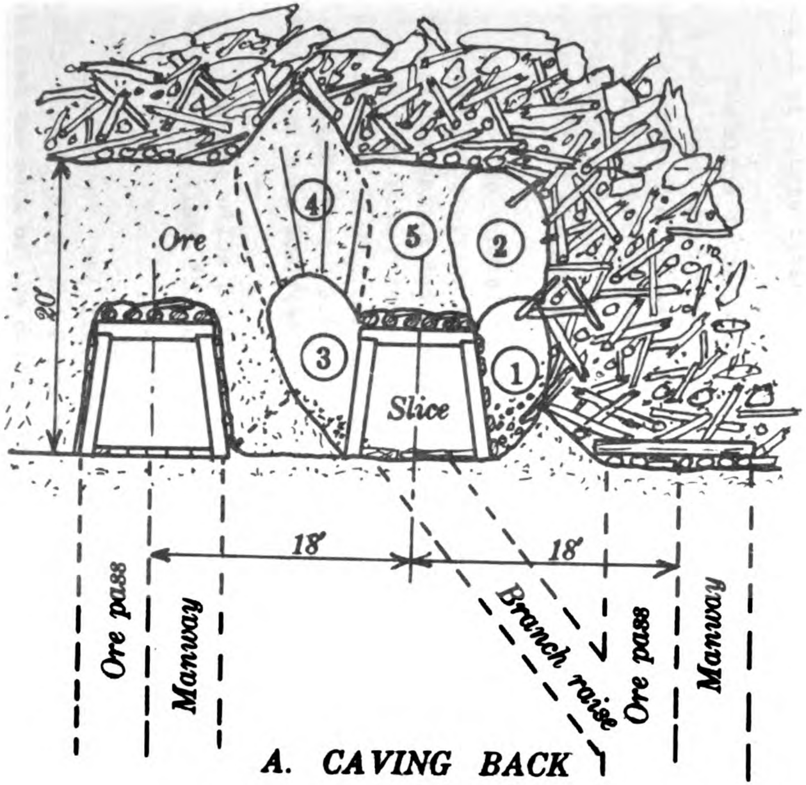


LONGITUDINAL SECTION ON FOOTWALL

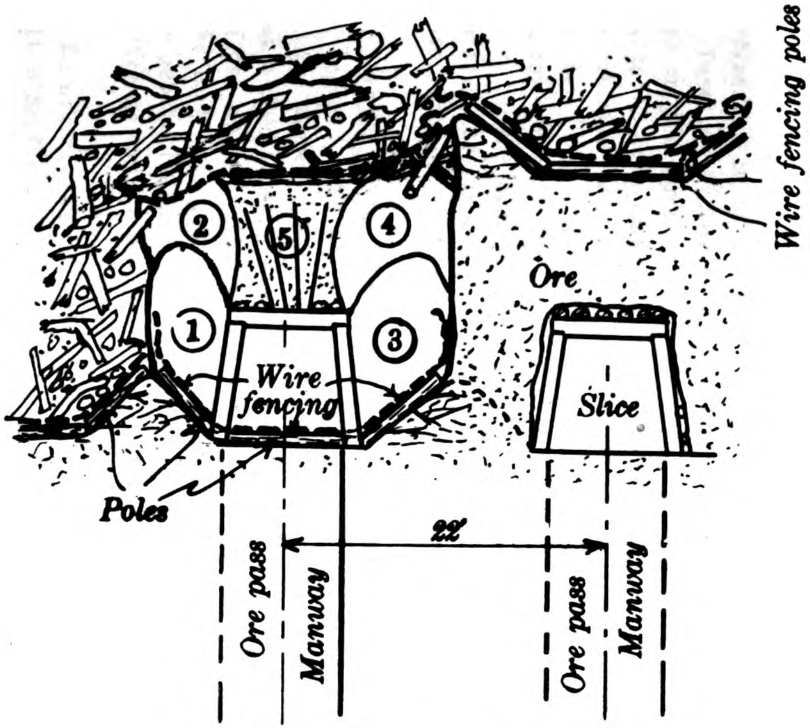


SECTION 1150 W

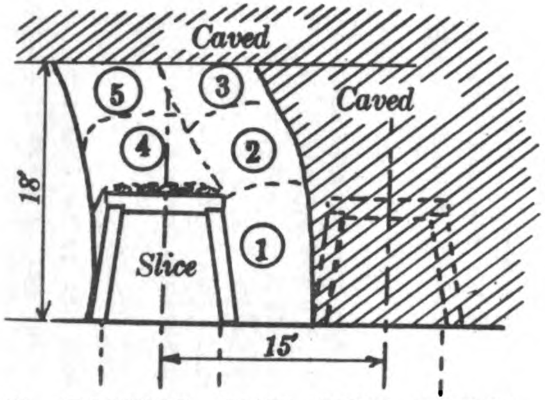
Figure 22.—Sections showing methods of developing ore body



A. CAVING BACK



B. POLES AND WIRE FENCING



C. CAVING ONE SIDE ONLY

Figure 23. – Cross sections showing "caving back" operation

val is ordinarily 18 or 20 feet to provide for straight scraping from the slices and caves.

Development for slicing and stoping begins on the top sublevel and is subsequently duplicated on the lower subs. A timbered drift is driven on the sublevel connecting the raises to serve as a communication drift or "timber drift," as it is commonly termed (fig. 21). The sublevel interval is usually 18 to 25 feet but is sometimes greater. At one mine[6] the higher sub is employed in the narrow ore bodies to partly equalize the sublevel development cost per ton with that for wider ore bodies. Here the interval between raises is up to 200 feet in narrow blanket ore bodies on the footwall. In ore over 100 feet wide raises are customarily driven 50 feet apart along the strike with branched raises therefrom to split the pillars between them. (see longitudinal section (fig. 22).)

Slicing and Caving.- In the very narrow ore bodies, caving starts midway between a pair of raises. The lagging is removed over two sets of timber and a 6-foot cut is taken in the back. Miners stand on the broken ore to drill the next cut. Before blasting this second cut a few lagging are put back over the sets to prevent any premature runs of gob. Where the ore is a little wider, caving is started first on the hanging-wall side of the drift. Two long cuts are blasted on the hanging-wall side first and then two on the footwall side. The gob is reached on the second cut. The ore directly over the drift timber usually becomes heavy by this time and one blast will bring it down up to the gob.

In ore bodies of moderate width, where the line of raises is parallel with the strike, slice drifts are driven from the raises on the sublevels, toward the foot and hanging walls. It is usual to drive to the hanging wall first. In the narrower ore bodies of this type the raises and connecting sublevel drifts may be right on the footwall, in which case slicing is of course toward the hanging wall only (fig. 21C).

The slice drift is an ordinary timbered drift with sets of round timber spaced on about 5 or 6 foot centers and lagged over the top with split lagging. Posts and caps are ordinarily either 7 or 8 feet long and the posts are well battered. In very wide ore bodies where there are several lines of raises running across the ore body (fig. 21A) the slices are driven parallel with the strike in both directions from the raises and halfway through the pillar or block of ore between the raise lines.

Since the tops of the production raises or branches therefrom usually come out on each sublevel at intervals of 18 to 20 feet up to 25 feet, and the slice drifts are 8 to 10 feet wide at the bottom and are centered in line with the centers of the raises, a pillar of ore 10 to 12 feet wide remains between each pair of slice drifts. There is also a pillar of ore 10 to 15 feet thick, depending upon the sublevel interval, between the back of the slice drift and the gob above. Slice drifts are ordinarily 50 or 60 to 75 or more feet in length, sometimes as much as 150 feet.

When the slice drift has been driven to the hanging or foot wall or to the predetermined mining limit the "stoping back" or "caving back" operation is begun at the end of the slice.

A side cut (see fig. 23A) is first taken on the side next to caved ground and succeeding cuts 2, 3, 4, and 5 are taken as illustrated, the fifth or last cut being always the one over the back of the drift. In making these cuts, lagging is removed from one or two sets, as required, to permit drilling the cuts. The side cuts are driven up on an angle of 45 or 50° from the horizontal at right angles to the drift. Usually the cuts are started between the last two sets of timber, but in some instances they are begun between the second and third sets from the end of the slice. In blasting the side cuts (1, 2, 3, and 4) care is taken not to shake up the pillar over the back of the drift any more than is necessary. This back pillar can usually be brought down by removing the lagging and blasting one short round of holes in it. Sometimes in starting against a strong capping it is necessary to pull back several sets before the gob will come down.

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[6] - Sohaus, O. M., Information Circular 6348, cited.

Both during the advance of the slice drifts and the caving back operations the ore is scraped with power scrapers into the production raises.

Between slices a hogback of ore is left which is recovered later from the next sub below. At some mines the hogback is drilled and blasted before caving the gob but is not mucked out. In this event a mat is laid over it to prevent its mixing with the gob. At one mine visited this mat consisted of poles laid across the drift and covered with wire fencing (fig. 23B).

When the ore has been removed from the end of the slice and the gob is down, the operation is repeated in the next set back from the cave and so on till the slice is mined back to the raise, or to within about 8 feet of the raise if slicing is to be done on the opposite side. Sometimes caving is done on one side of the slice only, as shown in Figure 23C. In that event, for most efficient scraping the raises must be closer together than where both sides are caved.

The scraper hoist is usually set in line with the slice and on the opposite side of the raise from the slice, thus obviating the necessity of using turn sheaves.

In this method of mining the slice drifts and caving back proceed very rapidly, and indeed it is essential to successful operation that the work shall be rapid. As compared to top slicing the advance of the slices is more rapid since (1) standard timbering with shorter posts is used; (2) the slices advance in solid ground with ore on top and on both sides; (3) with a solid back of ore above, forepoling and catching up of the mat are not necessary as in top-slicing, though forepoles are often driven ahead after each round to protect the men from possibility of injury from falling ground while scraping out the ore from the face. In other words, the operation can be highly standardized.

It is usually arranged to have one slice caving back while the adjacent one is advancing. The men usually work in pairs. At some mines each pair or "contract" have only one slice or one caving operation. In others, two men may have one slice going ahead and one slice caving back. In yet other mines one contract may have two adjoining raises and all the slicing and caving tributary thereto. At one mine visited three men worked on a shift where there was more than one working face for each contract.

At another mine visited by the author two men on each shift did the mining tributary to two raises and were supplied with a complete scraper equipment for each raise so that while one miner was scraping out the ore in an advancing slice drift, the other was scraping out from the adjoining caving back drift. At this mine a complete shift's operation was observed during which two men, with the aid of two timbermen during the timbering cycle, drilled, blasted, mucked out, and timbered three times (three complete cycles) in an advancing slice drift about 8 by 10 feet in size, and in addition scraped out considerable ore from an adjoining caving drift. Each cycle advanced the drift 5 feet, about 30 tons of ore being broken by each round.

The cycle was about as follows:

	Minutes
Scraping	40 to 45
Timbering	30 to 35
Drilling	40 to 45
Loading and blasting	15 to 20
Blowing out smoke	15
Total	140 to 160

Usually the stope miners place their own timber, which is brought to their working place by timber trammers; but in other instances, as cited, a special timber gang is employed to place the timber with the assistance of the miners.

In caving back, a production of 40 to 60 tons per miner per shift is common, and 80 or more tons not unusual. At one mine the average tonnage per man over considerable periods for advancing and caving back combined was reported to be 40 tons.

Usually in these mines no attempt is made, once caving is well started and a good gob established, to cover the floors of the slices carefully, as in top-slicing practice. There are exceptions to this, however; at one mine visited by the author poles were laid across the slice between sets and up over the hogbacks, which had been previously drilled and blasted, and the poles were covered with wire fencing (fig. 23B). At other mines boards or plank are laid on the floor more to serve as a good bottom for the scrapers to work on than to form a mat. Sometimes when starting at the capping, old timbers are piled in the excavation to assist in starting a good gob.

Radial Slices.- Sometimes the slices are driven radially[7] as in top slicing, but this practice is being replaced in most mines by parallel drifts except under special conditions. Where radial slices are used the slices are driven alongside each other without intervening pillars.

Drilling and Blasting.- The ore is usually soft and is easily drilled with light hammer drills having a special rotation and using auger steel. The drills are usually held in the hands and most of the holes are breast holes, but sometimes are mounted on an automatic feed leg. Holes are loaded with 35 or 40 per cent gelatin and blasted with fuse and caps. Figure 14C shows a typical round in a slice drift and figures 23A and 23B illustrate a commonly used method of placing fan holes in caving back.

In rock development, medium or heavy Leyner-type machines with standard hollow drill steel and cross bits are employed.

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[7] - Funkey, C. H., Mining Methods of the Castile Mining Co.: Proc. Lake Superior Mining Inst., vol. 25, 1926, p. 140-141 and sketch No. 1.

Best, Byron G., The Gogebic Range Mines of the Oliver Iron Mining Co.: Proc. Lake Superior Mining Inst., vol. 25, 1926, pp. 75 to 111 and figs. 15, 16, 17, 18, and 19.

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Timbering.- Slice timber is usually in 7 or 8 foot lengths and varies in size from 8 or 10 inches at some mines to 12 or 15 inches in others. Most of the timber is unbarked tamarack with smaller amounts of hemlock and hard woods. White birch, although sometimes used, is objectionable. Yellow birch, on the other hand, is preferred by some mining captains. The lagging is mostly cedar, tamarack, or spruce in the round or split form. Pine which was much used in early years is not now obtainable nearby and is too costly when obtained from distant sources of supply.

The timber is usually framed by hand on surface. The framing is the same as that for top-slice sets except that since the posts are always set at a good batter, the joggles are cut at more of an angle. It will be recalled that in top slicing, particularly on the Mesabi Range, the posts are often set almost vertically.

Timber and lagging are delivered to the working places by timber trammers who employ small air tuggers or the regular scraper hoists to pull it up into the places from the main haulage level or in some cases from special timber haulageways.

On account of the depth and heavy ground in most of these mines, much retimbering, particularly of the connecting or timber drifts on the subs as well as on main levels, is required. Rapid working of the slices and caves is therefore desirable from the standpoint of timbering costs, since less retimbering is required on the subs if worked rapidly. It is also desirable in this connection to defer development of lower subs as long as possible, yet they must be ready when the ore above is worked out in order to maintain a steady rate of production. While in this ground a good production is obtainable from slice drifts, the most rapid output results from the caving-back operation. In the larger ore bodies a uniform rate of production can be readily maintained by having one side or end of the mine in advance of the other, with mining in progress at a given horizon in one section while developing this horizon in another section. In mines with smaller ore bodies the problem is not solved so easily, however.

Scraping Practice.- On the Gogebic, as on the other iron-ore ranges, scraping has replaced hand-shovelling and tramming entirely and the scraping practice is similar to that already described where the ore is scraped directly to chutes.

Equipment consists of double-drum hoists, hoe or box type scrapers, 3/8 and 1/2 inch flexible wire ropes, tail sheaves, etc. The tail sheave is secured at the face to either a steel boom, timber sprag or pole, or to an eyebolt inserted and wedged in a hole drilled in the face.

Double-drum electric tugger hoists are used and as on the other ranges the larger sizes of 15 to 25 horsepower capacity are becoming the standard sizes, the 15-horsepower units for mining and the 25-horsepower units for transferring ore on sublevels or loading from main level storage drifts.

Where the bottom of an ore body pitches up above the main haulage level for a considerable distance, expensive rock development is avoided by driving a transfer sublevel in ore above the main level and running up production raises therefrom for mining the upper subs The ore passes in these raises are open bottomed - that is, without chutes. The ore falls into the sub drift from a series of these raises and is transferred to a main-level raise by a large scraper. These scrapers ordinarily transfer 200 to 300 tons per shift or more.

At some places storage or scraper loading drifts are driven across between main level haulage drifts a few feet above the haulage level and are connected to the sublevels by open-bottomed raises (fig. 21B). The ore is then loaded into haulage cars by large scrapers. At one mine using this system the loading and haulage cost was 7 cents per ton less than that for loading from regular chutes.[8]

Comparison of Top Slicing and Sublevel Caving.- As previously stated, sublevel caving and top slicing are adapted to somewhat different conditions, especially as regards gob action. Top slicing requires a gob or mat which will come down quickly and fill tight. Sublevel caving requires that the gob shall hang slightly and that it shall not come down till the back of ore can be withdrawn from beneath it; otherwise loss and contamination of the ore will result.

In discussing the sublevel caving practice at the Montreal mine, O. M. Schaus says:[9] "The determining conditions to which this method of mining is adapted are: (a) A dipping and pitching irregular ore body which does not lend itself to top slicing; (b) A medium soft ore which breaks fine, yet stands well and is not free caving; (c) A hard capping which caves in medium-sized blocks without much fines, and which is easily controlled."

As was pointed out under "Vermilion Range," sublevel caving is being used successfully in very hard ore.

In general, sublevel caving may be said to have the following advantages over top slicing.

1. Less stope development per ton of ore developed because of the greater sublevel interval.

2. Lower timber consumption in the mining operation since only one-half, or less, of the ore is extracted from timbered openings, the balance being recovered from untimbered pillars between or over the slice drifts. Somewhat heavier timber is usually employed in sublevel caving, however. In comparing two different mines, one using top slicing and the other sub-caving there might be found little difference in the amount of timber consumed. This would be due more to local conditions and other factors than to the mining method, however.

3. Lower powder consumption, since much of the ore is caved or is brought down by only light blasts.

4. Less drilling per ton of ore mined.

The chief disadvantage of sublevel caving is that although in ground and under a gob well suited to sublevel caving, recovery is often complete and very little dilution of the ore occurs, in general as clean mining can not be achieved as with top slicing. In making this statement it must be emphasized, however, that although the two methods may sometimes be employed interchangeably, there are often gob conditions under which top slicing would not be safe. Where the gob hangs up and then comes suddenly in a large mass there would be no cushion of ore over the top-slice timbers to take up the shock, and top slicing would be very hazardous.

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[8] - Schaus, O. M., Mining Methods and Costs at the Montreal Mine, Montreal, Wis.: Information Circular 6369, Bureau of Mines. In press.

[9] - Schaus, O. M., Information Circular 6369, cited.

Cost and unit production data are given in the tables appended to this paper.

In discussing sublevel caving and cost savings as compared to top slicing and its attendant costs, the question naturally arises as to why block caving is not employed instead of sublevel caving in the iron mines of the Lake Superior region. There may be places where block caving could be employed; in fact, block caving was used at the old Pewabic mine on the Menominee Range[10] before it was introduced in the copper mines of the Southwest.

Block caving has been employed for many years at the Tobin mine on the Menominee Range.[11]

Probably the chief difficulty in the way of a wider application of block caving to the mining of Lake Superior ores is due to the physical character of the ore. Most of the ores would, if broken and caved in large blocks, pack and stick together, making removal through chutes difficult if not impossible and producing piping through of waste with attendant high dilution and low recovery. This is particularly true if the ore becomes wet, as it almost invariably does when the capping has been broken, thus letting in surface water. Most of the ores have an appreciable inherent moisture content and as shipped carry about 10 to 13 per cent moisture on the Gogebic Range, 7 to 10.5 per cent on the Marquette Range, and 6 to 8 per cent on the Menominee Range.[12]

5. Marquette Range

On the Marquette Range, Mich., the soft ores are mined usually by top slicing but sometimes by sublevel caving. The ore bodies are enriched portions of iron formation in minor folds or troughs superimposed on a wide, westward pitching synclinorium or at the intersection of diorite dikes. The iron formation consists of ferruginous cherts and slates intruded by dikes and sills of diorite.

The footwall formation is usually the Siamo slate which contains some cherty, ferruginous phases. The footwall is usually quite regular, but irregular lenses and chimneys of ore often extend upward into the overlying iron formation, and the upper boundaries of the ore bodies are not sharp. The overlying beds of chert and jasper are hard but quite friable and when caved, break into a medium-sized rubble. The rocks of the area are overlaid by thick glacial drift in most places. Present mining operations are at depths varying from less than 1,000 feet to about 2,500 feet, so that the pressures encountered in top slicing are often considerable.

Individual ore bodies vary in size from narrow lenses to bodies 800 feet wide and 150 feet or more thick.

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10 - Wilson, J. B., Caving Systems of Mining in America: Eng. and Min. Jour., vol. 94, 1912, p. 245.
Myers, A. J., The Block-Caving System Used at the Pewabic Mine: Proc. Lake Superior Min. Inst., vol. 21, 1916-1917, pp. 25-28.

11 - Roberts, Fred C., Block Caving and Sub-Stope System at the Tobin Mine, Crystal Falls: Proc. Lake Superior Min. Inst., vol. 16, 1911, pp. 218-226.

12 - Crowell and Murray, Inc., The Iron Ores of Lake Superior: The Penton Press Co., Cleveland, Ohio, 7th ed., 1930, pp. 71-78.

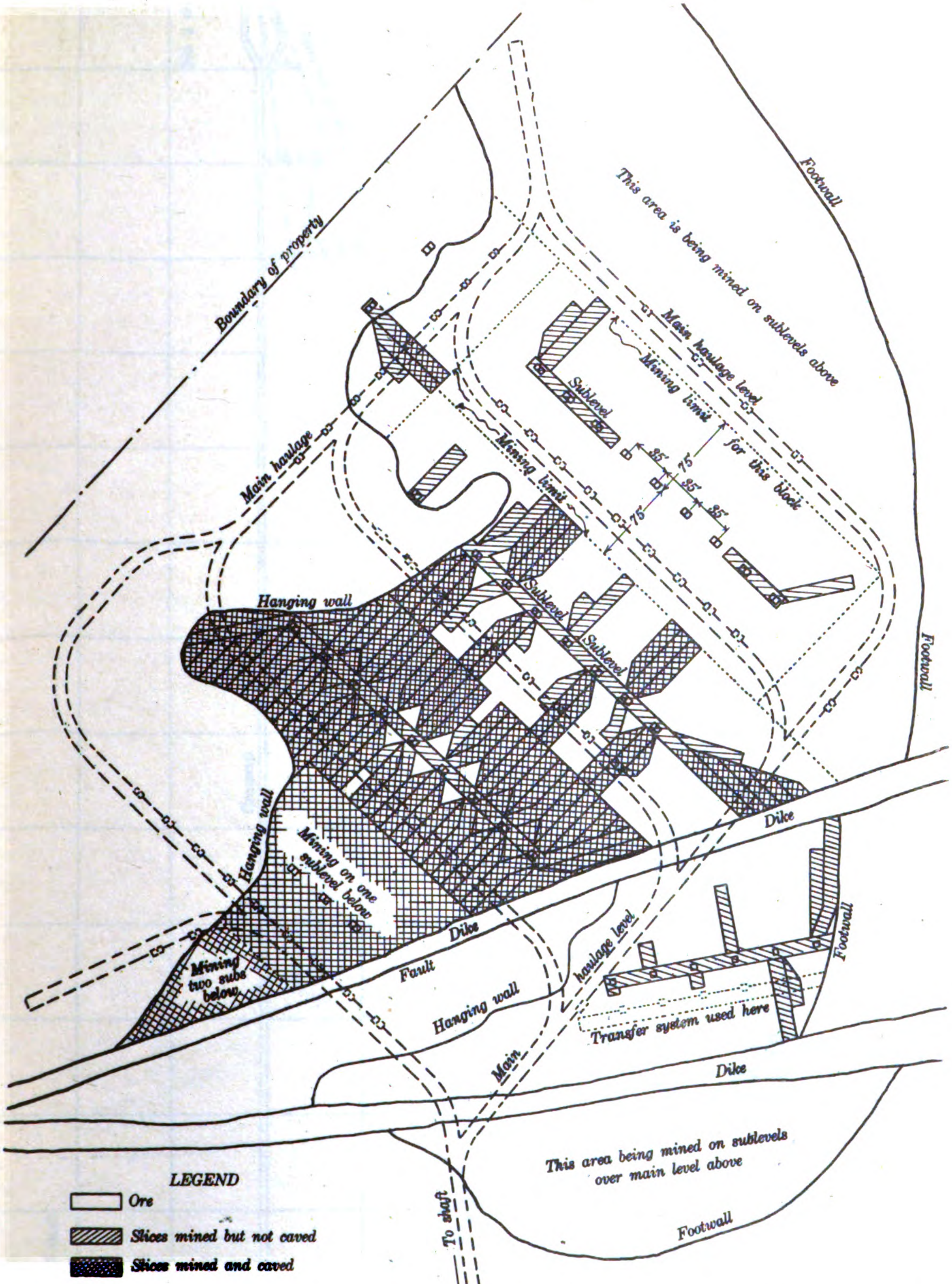

Figure 24. – **Plan of typical sublevel,** *Marquette Range, showing main level development and arrangement of slices in mining blocks*

0 25 50 100 150
Scale in feet

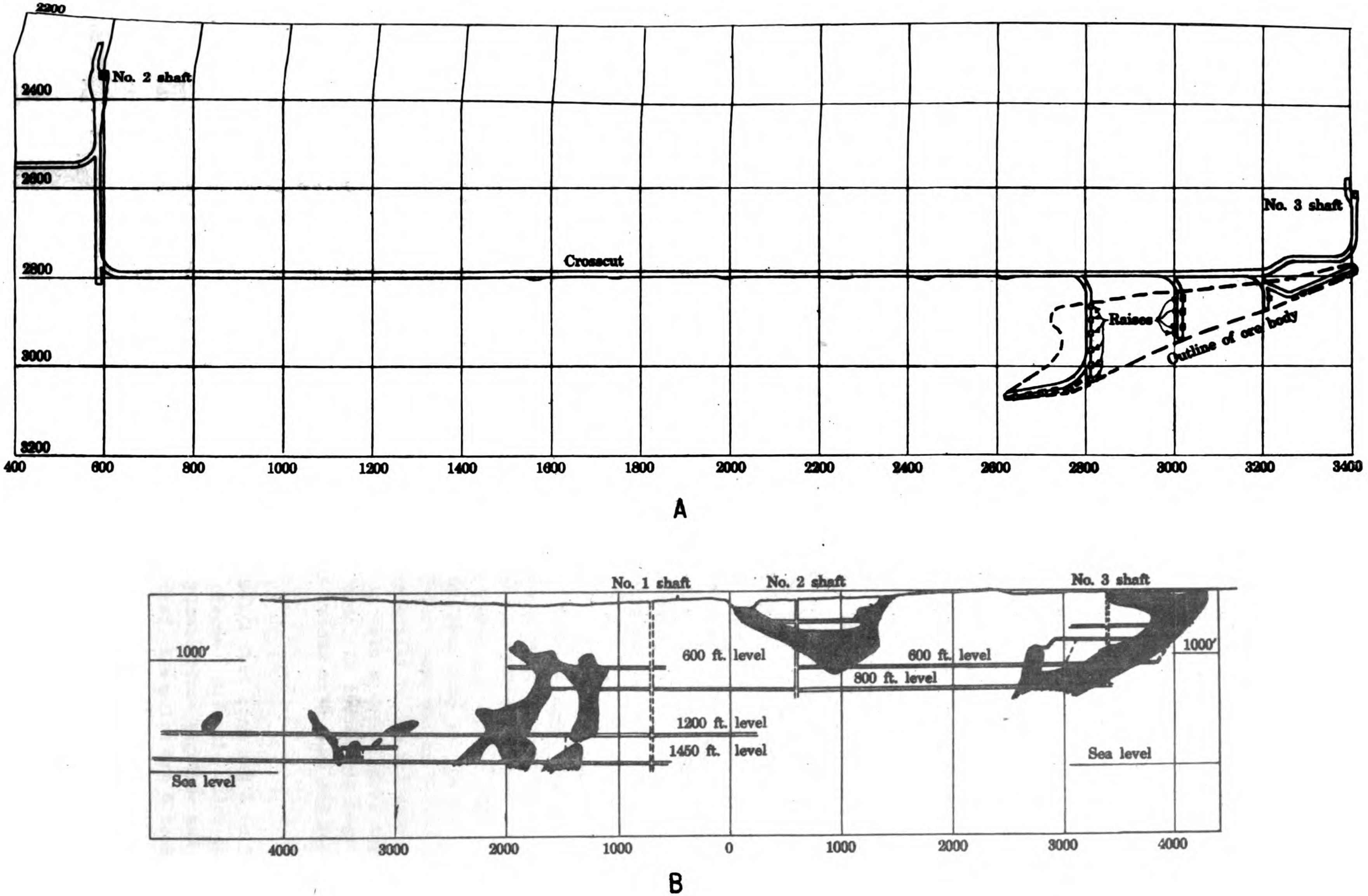

Figure 25.- A, Plan of a main level; B, longitudinal projection of mine

Development.- The mines are developed by vertical shafts from which main haulage levels are driven at vertical intervals of 100 to 250 feet. Where these level intervals are high, the ore lenses are usually small and irregular in shape, and intermediate transfer levels are driven. Figure 24 shows a wide ore body developed by a loop-haulage system with cross drifts spaced at 150-foot intervals. Figure 25 shows a narrow ore body developed by a longitudinal footwall drift with crosscuts through the ore at 200-foot intervals.

From the haulage drifts two-compartment cribbed raises are driven, usually at an angle of 65 to 70°, to develop and mine the sublevels. These raises are spaced from 30 to 100 feet apart, the larger interval being used in narrow bodies of ore and where radial slicing is employed. These raises are connected by timber drifts on each sublevel, and the work begins on the upper levels first. The sublevel interval is usually about 10 to 13 feet.

Top Slicing.- The top slicing practice used on this range is similar to that already described as employed in other of the Lake Superior iron districts.

At one mine[13] where the ore is in the form of a steep lense about 100 feet wide, radial top slicing is employed. Figure 5B shows a sublevel developed by a tramming drift connecting a line of raises down the center of the ore body. Slices 10 feet high are taken by radial drifts from the top of each raise in the order shown. Several slices can sometimes be mined before taking much weight on the timbers. The floor of each slice is carefully covered before blasting down the timbers. Round poles 3-1/2 inches in diameter and 9-1/2 feet long are laid side by side and overlapped 2 feet on the ends. On the two top subs these poles are covered crosswise with 8-foot lagging to establish a good mat. The ore is soft and is drilled with light jackhammers and auger steel. Sixty per cent gelatin is employed in blasting to break the ore fine for ease in handling with scrapers. The ore is scraped to the chutes with 42-inch hoe-type scrapers weighing 325 pounds and pulled by 7-1/2 to 10 horsepower tugger hoists.

At another mine[14] (fig. 24) operating in a wide, deep ore body, parallel slicing with direct scraping to chutes is employed. The raises are 35 feet apart and three slices are mined on each side of the timber drift (or six slices in all) from each raise. The slices are 65 to 70 feet long and are timbered with 9-foot posts and 9-foot caps, the posts being set with an 18-inch batter, thus making the slice 12 feet wide at the bottom. The sublevel timber drifts are timbered with 8-foot posts and 8-foot caps set on 5-foot centers. After a breast in a slice is blasted, the back is trimmed carefully to the mat above, and at least three fore-poles 5 or 6 inches in diameter are put in with a covering of lagging to catch up the mat. On sublevels in heavy ground, no caps under 12 inches, or legs under 9 inches in diameter are permitted. Opening sets or sets at raises have caps and legs 12 to 14 inches in diameter.

The floors of the slices are covered with poles 9-1/2 feet long and 3 to 6 inches in diameter laid along the drift and spiked to three cross pieces. Directly under the hanging wall or near dikes or horsts of jasper, these poles are placed close together and covered with cross-lagging. Where there is already a good mat overhead, the poles are 6 to 8 inches apart. The poles form a good floor to scrape over and make a good solid mat to work under

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13 - Eaton, Lucien, Mining Soft Hematite at Mine No. 2 of the Marquette Range, Michigan: Bureau of Mines, Information Circular 6179. 15 pp.

14 - Graff, W. W., Mining Practices, Methods and Costs at Mine No. 5, Marquette Range, Mich.: Information Circular No. 6380, Bureau of Mines.

on the next sub below. The practice of spreading wire fencing over the poles before blasting down the slice has recently been instituted as the fencing forms an even more secure mat.

In some sections the capping tends to hang up over considerable areas. Under these conditions it becomes necessary to drill the back and blast it down. It is not deemed safe to continue slicing below until a thickness of at least 20 to 30 feet of broken capping is accumulated to act as a cushion for protection of the lower slices against sudden collapse of blocks of capping.

All the ore is handled by scrapers and only one set-up of the hoist is required for three slices. Electric double-drum scraper hoists of 15-horsepower capacity are standard equipment at this mine. The scraper is of the box type with a manganese steel lip having a 36-inch maximum width and a 33-inch cutting edge; the sides taper both toward the bottom and toward the front. The tapering was found greatly to increase the ease with which the scraper fills itself when handling this particular ore. The side taper helps the scraper around curves or sharp turns.

Athens Mine.- At the Athens mine a top-slicing system is in use which is the reverse of the usual system in that mining starts at a block in the lowest section of the mine and advances in successively higher blocks up the pitch of a flat-pitching ore body. Slicing in a given block is from the top downward, as in the ordinary system. Following is an abstract of a paper in which S. R. Elliott[15] describes the system:

> The Athens system is based on the principle that in a mine under deep rock cover, actual caving to surface often takes years to accomplish. If slicing is started in the upper section of the mine and the surface is covered by a heavy mantle of sand and gravel saturated with water, this water and sand will start to find its way into the mine as soon as the rock capping breaks, which will be at a much earlier date than if slicing were started in the deepest section of the mine. Then as mining progresses downward, the burden of pumping will steadily increase, as will the weight to be controlled. To overcome this objection the Athens system was devised (fig. 26). The system is practicable only in a comparatively flat deposit.

Elliott states that the principal argument against the system is the interest on the original investment. He expected this disadvantage to be offset as follows: (1) By avoiding prohibitive pressures, thus making a large saving in timber cost. (2) The ore body will be drained and no surface water will pass through the working places because if caves to surface occur they will be below the active workings. By draining the ore and providing dry working places the efficiency will be increased and the cost lowered. The saving in freight by shipping dry ore will amount to a large sum of money over a period of years. (3) Pumping will be less than in the usual system because it will take years to break the surface. After the cave occurs and the size of the hole on the surface increases, draining a larger area, the pumping head will be decreasing as successive levels are abandoned. (4) It is thought that the system is safer than the ordinary system because a large proportion of the gangs are always working under a solid capping.

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15 - Elliott, S. R., Athens System of Mining: Trans. Am. Inst. Min. and Met. Eng., vol. 66, 1921, pp. 220-223.

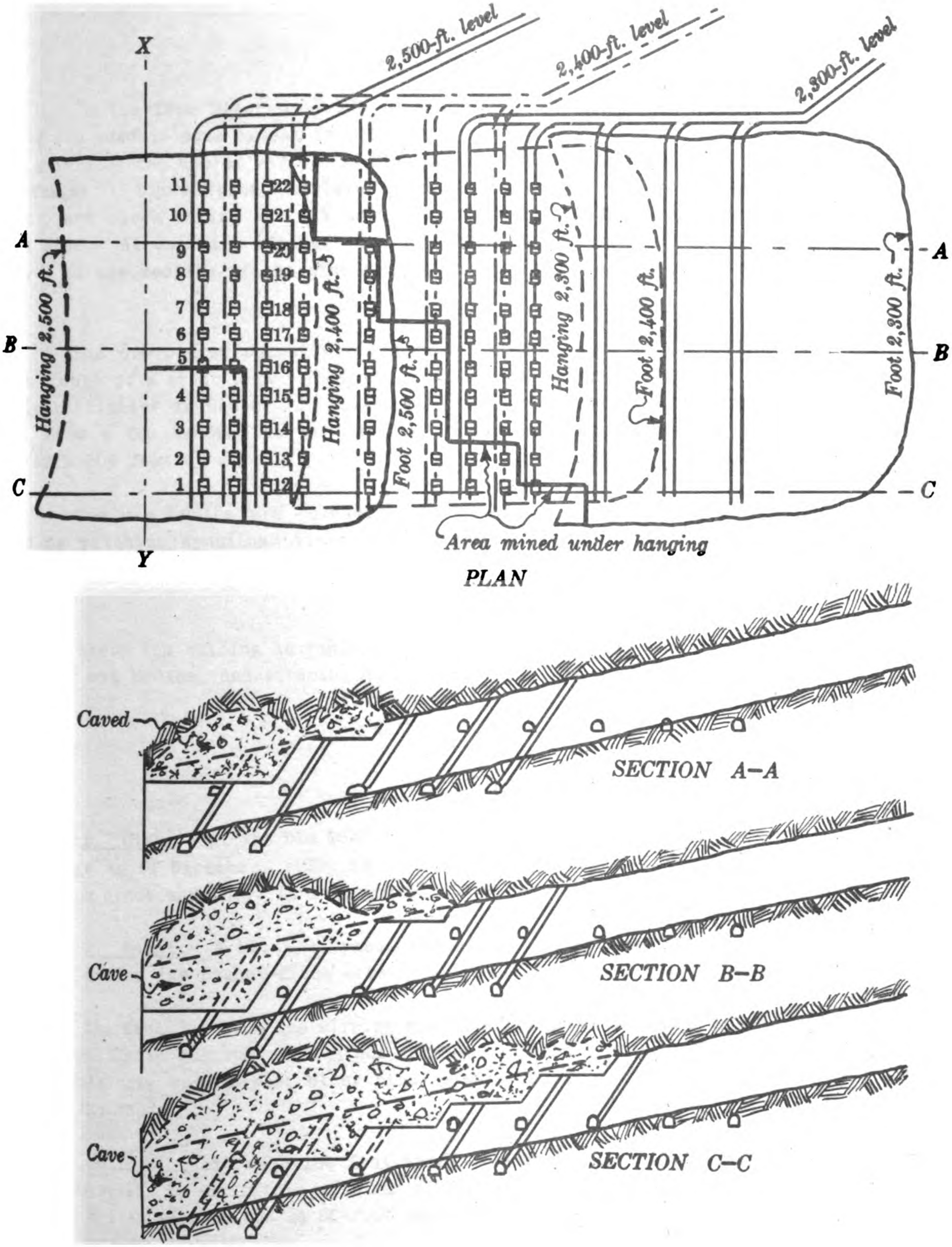

Figure 26. – *System at Athens mine (after Elliott, S. R., The Athens System of Mining: Trans. Am. Inst. Min. and Met. Eng. vol. 66, 1921, pp. 220-223)*

6. Menominee Range

In the Iron River district on the Menominee Range both radial and parallel top slicing are used to some extent in soft ores under glacial drift or weak cap rocks. Conditions governing the use of various mining methods vary more on this than on any of the other iron ranges. Top slicing, sublevel caving, shrinkage stoping, sublevel stoping (open stopes), and block caving are all used, sometimes two or more methods being employed in a single mine. At one mine visited, top slicing under a thick water-bearing sand was being employed in one section of the mine and in another section open sublevel stoping was going on.

The ore bodies commonly occur on one limb of a major fold but often occupy the entire trough of a minor fold. They are usually very irregular in outline but are frequently roughly lenticular in shape. In size they vary from a few feet to several hundred feet in width, from a few hundred to two or three thousand feet in length, and some extend to a depth of 1,500 feet or more.

The ore bodies are closely related to structural features and lie in basins formed by pitching synclines where the slates interbedded with the iron formation or the footwall slates have formed impervious layers controlling the circulation of underground waters.

Where top slicing is employed the method is similar to that already described for the deeper ore bodies, and scraping direct to chutes is the general practice.

OTHER EXAMPLES OF TOP SLICING

B - Arizona

1. Globe.- At the Old Dominion mine, Globe, Ariz., a small tonnage (about 3.8% of the tonnage as of December, 1929) is mined by top slicing. This method is used where the ore is high grade and where it is permissible to cave the overlying ground.[16]

2. Miami.- A block or panel system of top slicing was at one time employed at Miami for mining the higher-grade ores.[17]

The area in which top slicing was used was about 800 feet square. The ore was for the most part soft but was considerably harder than the capping. The latter was siliceous, seldom containing any clay or other binding material so that it broke into fine particles and ran like sand.

Haulage levels were 150 feet apart vertically with two intermediate sublevels at 50-feet intervals to facilitate building of chutes and for ventilation during slicing. Haulage-level drifts were driven on 50-foot centers and raises were put up along these drifts on 50-foot centers.

For slicing, the area was blocked out into mining units 200 to 250 feet square after it was found that in working a long face of retreating slices the entrance drifts, which had to be kept open for a long time with this system, took weight and required a large amount of retimbering and interfered with mining operations.

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[16] - Shoemaker, A. H., Mining Methods at the Old Dominion Mine, Globe, Ariz.: Bureau of Mines, Information Circular 6237, 1930, pp. 7 and 14.

[17] - Deane, E. G., Block Method of Top Slicing at Miami: Min. and Sci. Press, Oct. 21, 1916, pp. 601 - 602.

At the center of each block (fig. 6), a two-compartment supply raise was put up. Four bulkheads were placed as shown in section 1 of figure 6, and drifts were run to the boundaries of the block. The sequence of the slicing operations was as shown in the illustration. Slices were timbered with sets consisting of two 8-foot posts and a 12-foot cap or with double sets of three 8-foot posts and two 7-foot caps. The height of the slices was 10 feet.

As soon as the first slices had advanced a few feet, second and third slices were started and also first slices toward the centers of the block limits. Where a good mat had not been established a floor of 2-inch plank was spiked to 2 by 10 inch sills. Where there was a good mat no floor was laid in the slices before blasting down.

When the slice timbers showed signs of taking weight, bulkheads of old timbers were built at the entrance to the slices, and the posts were drilled and shot down.

When the last of the ore in a block was being taken, crosscuts were driven to inclined raises put up to about the center of the four central pillars (sec. 3, fig. 6) and slicing was continued, working from the outside of the remaining ore toward the central supply raise.

The ore was shoveled by hand into wheelbarrows and dumped into the raises.

This system had an advantage in that a large number of working places could be concentrated in a comparatively small area and the blocks could be worked out very quickly, thus reducing retimbering and maintenance. Deane states that as compared to the first system tried, using long faces, the production per shoveler-shift was raised from 9 to 20 tons and per man-shift, from 5 to 10 tons.

3. Morenci - Inclined Top Slicing.- In 1910 top slicing and sublevel caving were used at the Metcalf, Morenci, and Coronado mines in addition to open stopes, cut-and-fill, and square-set stopes.[18] Flat or horizontal slicing was used at this time with a sublevel interval of 9 to 11 feet. Before starting to top-slice two or three floors of square-set stopes were first taken below the capping to level off the top of the ore body and a good timber mat was established under which top slicing was begun.

In 1917 an inclined top slicing method was in use in the Coronado Mine[19] (fig. 4).

The following description is taken from Information Circular 6107, U. S. Bureau of Mines, 1929, page 14.

> In 1917 an inclined top slicing method was in use in the Coronado mine of the Arizona Copper Co. This method had the advantage

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[18] - Mosier, McHenry, and Sherman, Gerald, Mining Practice of Morenci Branch, Phelps Dodge Corporation, Morenci, Ariz.: Bureau of Mines Information Circular 6107, 1929, 33 pp.

[19] - Scotland, P. B., The Coronado Top Slicing Method: Eng. and Min. Jour., vol. 103, April 7, 1917, pp.561-562.

of eliminating all shoveling of ore in the stopes. The broken ore was blasted down on the sloping floor of the stope from which it ran into a narrow shrinkage stope at the bottom of the trough. The ore from the shrinkage stope was drawn directly into cars through chutes on the motor haulage level. As a result of the substitution of inclined top slicing for flat top slicing, the tons of ore mined per man shift in top-slice stopes increased from 4.90 in 1916 to 11.20 in 1917. The total cost of labor and material decreased from $1.06 to $0.75 during the same period.

A variation of the same method of inclined top slicing was adopted in the Humboldt mine at Morenci in 1918. At this mine the development work consisted of running sublevels at 55-foot vertical intervals and extending raises from the sublevels to the stopes. Each sublevel had a central drift through the ore body, with crosscuts at right angles to it at 50 or 60-foot intervals. From the latter, untimbered raises not over 4 feet in diameter were put up every 15 feet. These lines of raises formed the center lines of the individual slices. In stoping, an inclined heading was driven 44 feet above the sublevel, starting at one end of the line of raises. This heading was timbered with sets 11 feet high and 2-1/2 feet apart. As soon as the heading had gone far enough to intersect four raises stoping was begun. The ground was taken out in panels 10 feet wide and 50 or 60 feet long, corresponding to the distance between drifts on the sublevel. The floor of the panel was inclined 33° up on either side of the center heading, and the floor of the heading was funneled down to raises, so that ore blasted from the faces of the panels would run into one of the raises without any handling. When the heading had advanced to open another raise, which completed the panel, the timber was blasted and another started. Posts in the panels were 8-inch round timber, 10 feet long, on 4-foot centers up the incline and 5-foot centers parallel to the heading. These posts were not set normal to the floor of the panel but inclined toward the center heading at an angle of 16-1/2 degrees from the vertical. Flooring consisted of 2 by 12 inch planks laid upon sills of round timber. The sills were so placed as to be readily picked up by the posts of the next lower slice. The ore was drawn from chutes on the sublevel and hand-trammed to motor-haulage pockets. The substitution of inclined top slicing for flat top slicing resulted in increasing the tons mined per man shift from 5.4 in 1917 to 8.8 in 1919. The timber consumption was 7.9 board feet per ton with flat top slicing and was 9.0 board feet with inclined slicing. The total cost showed a reduction of 15 per cent in favor of the inclined method.

It would seem that with the development of underground scraping practice to its present efficiency and with the highly developed scraper hoists of to-day, any advantage that inclined top slicing might have formerly had over horizontal slicing no longer exists.

The labor of handling and installing timber, drilling equipment, and gear on the inclines, and the difficulty in working on a sloping floor as compared to working on a flat floor are disadvantages of the inclined top slicing system. Tons per man in flat slicing using scrapers averages about 15 tons (2,240 pounds) in the Lake Superior districts as against 11.2 tons (2,000 pounds) for inclined top slicing. Also inclined top slicing at the Humboldt mine required more timber than flat slicing, as has been shown.

4. Bisbee.- About 1914 it was decided that the top slicing method employed at that time on the Mesabi Range might be applied to a large body of oxide ore in which heavy and swelling ground made the cost of square-set stoping excessively high.[2]

The fact that there was no working level above this ore from which stopes could be filled also contributed to the choosing of the top-slice system. The method worked with some degree of success and reduced the cost of stoping substantially. In order to reduce the large amount of handling of ore in stopes, a variation of the usual top slicing system was evolved which has come to be known as the Mitchell top-slice caving system (fig. 27), from the name of its originator.

The following is an abstract of Wilson's article referred to:

> The ore body is laid out in 45-foot sections at right angles to its general strike, the length of the sections being the width of the ore body up to a maximum of 80 feet and 100 feet being the economic limit in height.
>
> These sections are developed by and mined through a pair of double compartment (chute and manway) timbered raises (g - f, fig. 27). From the chute compartment, parallel lead rows of square-sets are carried the width of the ore or of the section on the three floors beneath the hanging wall. On each succeeding floor below these the square-sets are carried for a shorter distance to leave a footwall of unbroken ground sloping toward the chutes in the main haulage drift. A pillar 40 feet wide is left which is mined by horizontal slices from the top downward, one half being taken from each side. The back is caved as stoping progresses. Slicing starts at the end of the pillar farthest from the main drift, and the first slice is timbered with square-sets. The first slice-cuts into the pillar are taken at an angle of 45° from the horizontal and the bottom is floored with 2-inch plank laid on stringers set at 45° on solid ground. As the slicing retreats toward the main drift, the rows of square-set posts first erected are shot out and the back is caved, leaving at all times at least two open sets between the working face and the caved ground. Bulkheads resting on the inclined stringers are built as required to relieve the weight on the square-set timbers. When the upper slice has retreated far enough so that the first caved ground has become solid, the next slice below may then be started.
>
> As slicing proceeds downward, the lower floors of the vertical lines of sets must be extended to maintain the slope of the solid ground to the extreme end of the section and permit the ore to run readily into the chutes. As mining approaches the sill floor, additional chutes may be put in the sill sets to facilitate drawing the ore

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20 - Wilson, Philip D., Stoping in the Calumet and Arizona Mines, Bisbee, Ariz: Trans. Am. Inst. Min. and Eng., vol. 55, 1916, pp. 127-131.

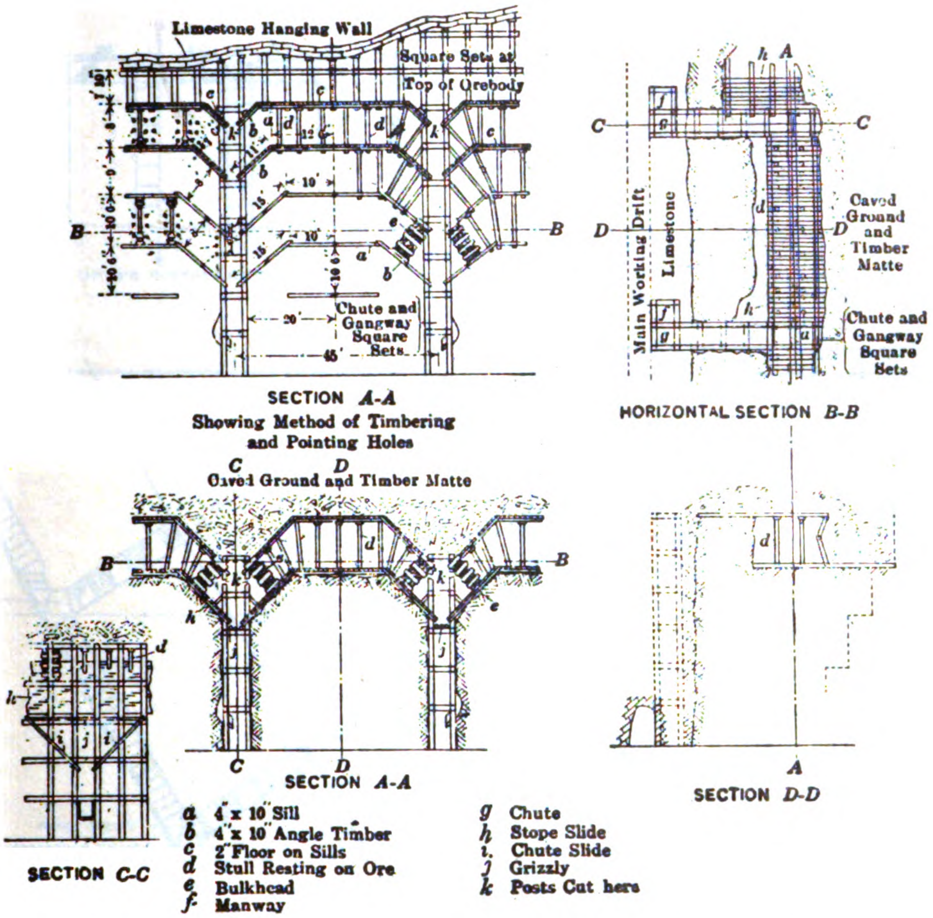

Figure 27.- Mitchell top-slicing caving system

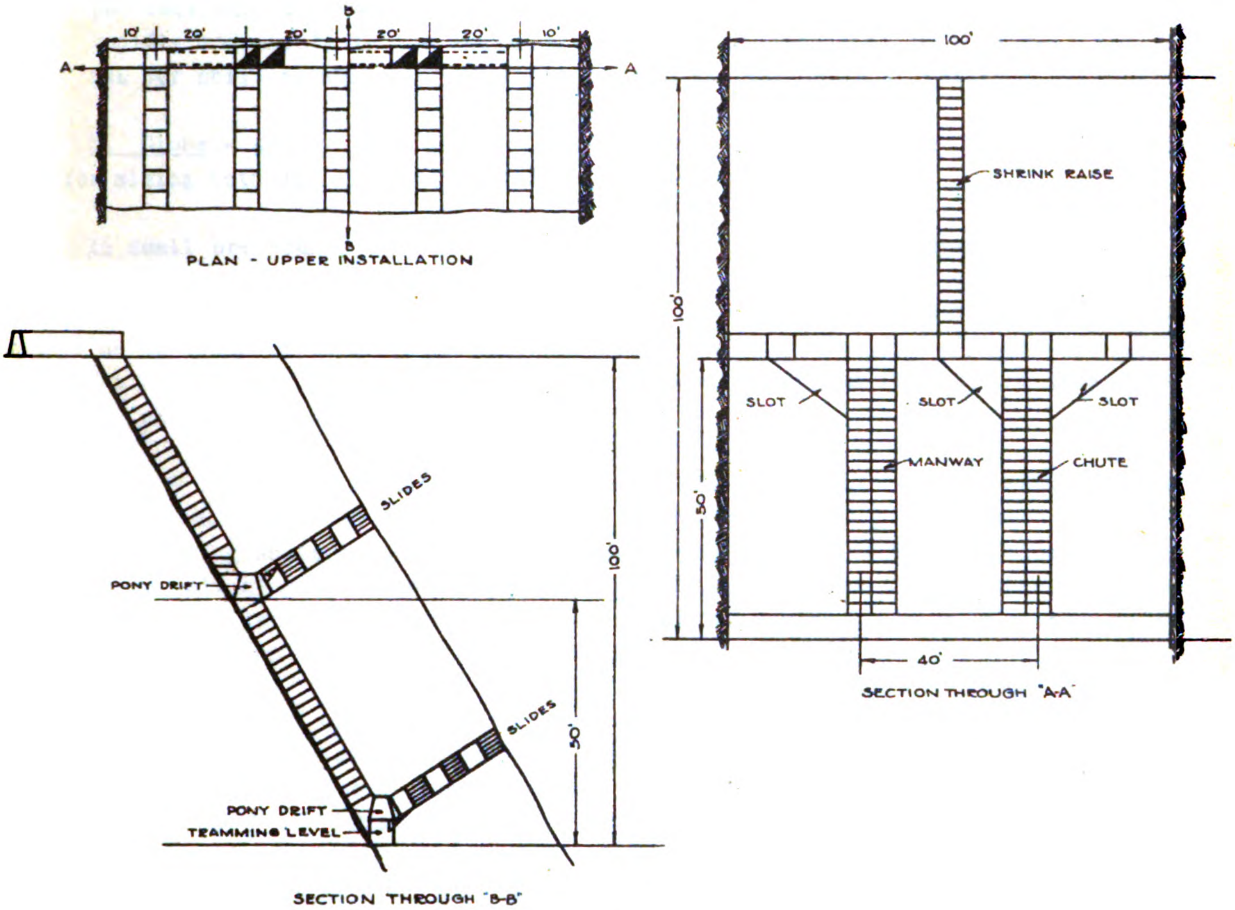

Figure 28.- Typical caving stope, Old Dominion Co.

by gravity. It was found that the maximum thickness of slice which could be safely carried was 10-1/2 feet, and this thickness was not attempted until the fourth slice was taken and the caved mat under perfect control. A 10 per cent reduction in stoping cost was realized as compared to ordinary top slicing; the labor cost was reduced about 15 per cent and the powder consumption was less. The ore could be mined rapidly and safely in the heaviest ground and an output of 10 tons per man per shift or about 125 tons per section per day could be obtained.

5. Globe.- At the Old Dominion mine a caving system known as the Morenci slide is used for mining both small and large bodies of low-grade ore.[21]

In small ore bodies this method is analogous to sublevel caving as practiced on the Gogebic Range and may be considered an adaptation thereof. The chief difference is that the sub height is greater and the sublevels are not level but inclined (fig. 28). Thus, instead of using scrapers to drag the ore over level drifts to the raises, the ore runs by gravity. The ore between the inclined slices is drilled and caved in much the same manner as in regular sublevel caving.

Table 6 on page 21 of Information Circular 6237 shows tons per man-shift obtained by the Morenci slide cave to be 17.3 short tons. In Table 6 of the present paper, mines 17, 18, and 20, employing sublevel caving, show respectively 0.411, 0.352, and 0.365 man-hours per long ton for all stope labor or 19.5, 22.7, and 21.9 long tons per man-shift. At Mine 20 (not shown in this table) where conditions are ideal for sublevel caving, the average tons per man-shift stoping is reported to average 40 long tons.

The sub interval of 50 feet at the Old Dominion mine as against 18 to 25 feet at the mines using regular sublevel caving is an advantage partly offset by the longer average slice length at the latter mines. The efficiency of the level scraper system would appear to be fully as great as the inclined gravity method.

C - Mexico

1. Cananea.- At the Capote and Veta Grande mines[22] square-setting and top slicing have accounted for most of the tonnage to date. Here the ore bodies are irregular in size and shape and the wall rock is generally weak.

In the Colorada mine[23] top slicing will be applied to mining pillars between finished cut-and-fill stopes.

Catron describes the details of the method as follows:

> These pillars will be 40 or 50 feet wide and 60 to 100 feet or more long. They will be already partly developed by drifts along their center lines and by raises from these drifts, generally at 40-foot intervals. In addition, some of these raises will have inclined branches or fingers extending toward the edges of the pillars which have been used for drawing ore from the cut-and-fill stopes on the

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[21] - Shoemaker, A. H., Mining Methods at the Old Dominion Mine: Bureau of Mines Information Circular 6237, 1930, 21 pp

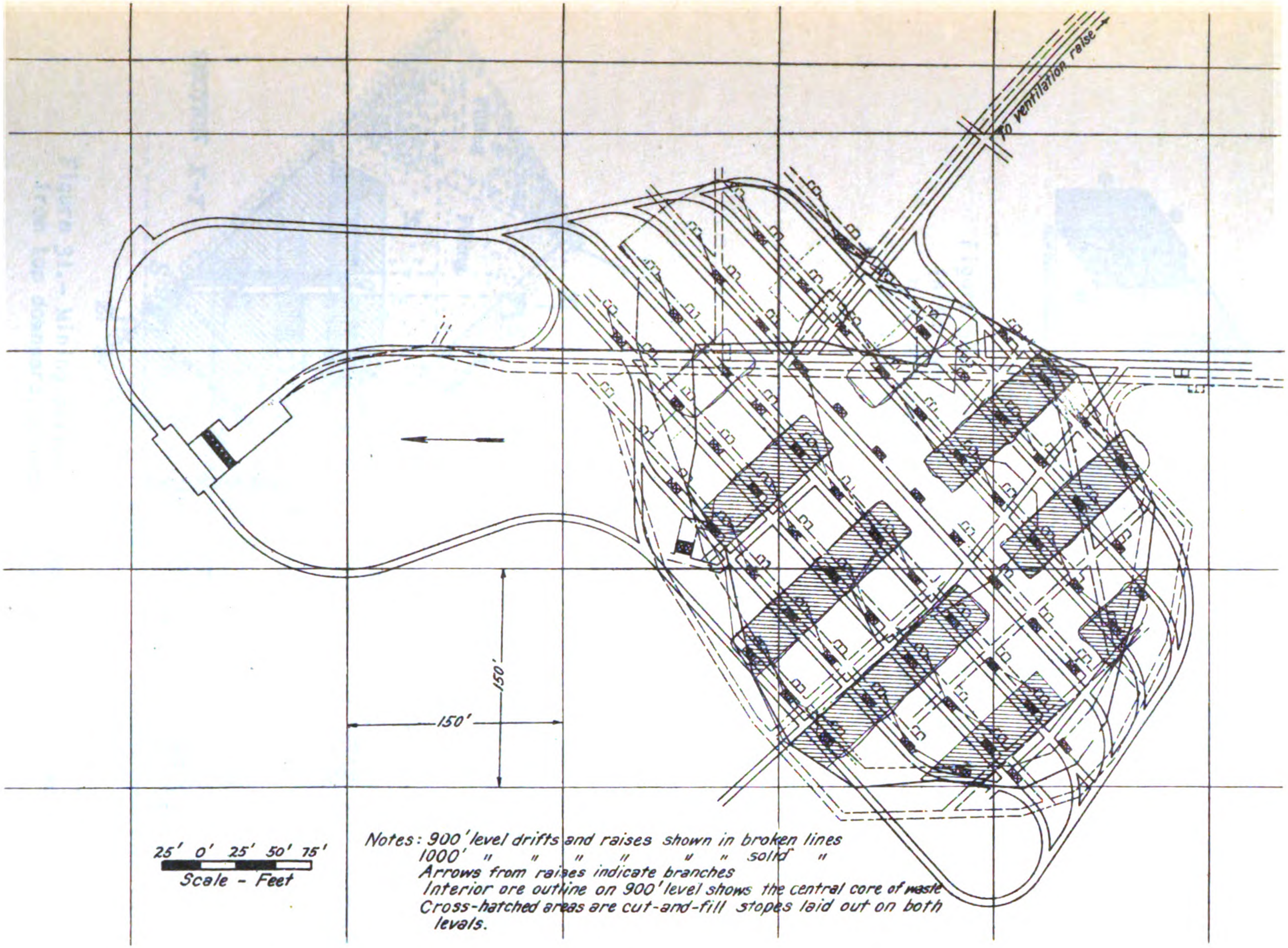
[22] - Catron, William, Mining Methods, Practices, and Costs of the Cananea Consolidated Copper Co., Sonora, Mexico: Bureau of Mines, Information Circular 6247, 1930, 41 pp

[23] - Catron, William, Work cited.

level above. Above the 900 level the pillars will be only 40 feet wide and disconnected. Above the 1,000 level, as shown in Figure 29, they will be 50 feet wide and spaced 30 feet apart along a central 40-foot pillar which runs through the long dimension of the ore body.

These blocks will be mined in one or two sections, depending upon the number of working places desired. One or two headings, therefore, will be driven lengthwise through the pillar on the top floor, intersecting the raises or the fingers, and past the end of the block into country rock where they will connect with a permanent manway raise They will be driven as small as possible, about 3 or 4 by 6 feet, leaving 5 feet of solid between them and the filled or caved stope above. Mining will be started at the end of the heading away from the manway. A 5-foot cut, 11 feet high (the standard height of top-slice floors), will be carried from the heading to the old fill or the dead line on either side. The sills of the old floor will be caught up by 8-inch round posts and head blocks. Long head blocks are used to spread the weight. Posts are stood on the ground without foot blocks. Another 5-foot cut will now be drilled and blasted. Slushers will be used to move the ore into the chutes. After each cut, or as often as an area at least 10 by 10 feet is available, floor will be laid consisting of 2-inch plank 10 feet long nailed to doubled sills of the same material. The sills are laid parallel to the direction of advance of the stope for convenience in picking them up when taking out the next floor. Two to four cuts (10 to 20 feet) will be taken out before shooting down, depending upon the weight that develops. In preparation for this, a light gob fence is built consisting of 2-inch plank nailed to the row of posts nearest the face. If the stope is being worked in two sections, it will be necessary to carry one section 30 to 40 feet ahead of the other and put up a similar fence along the dead line before shooting down the advance section. All posts except those in the gob fences will be drilled with air augers and blasted with a stick of powder each. These shots are timed so as to bring the floor down as smoothly as possible and more or less intact.

Headings are started on the floor below as soon as possible, so that when the first floor is finished mining can be started at once on the floor below. Possibly two or more floors may be worked at one time. In that case, it would be necessary to keep the lower floor at least 40 to 50 feet behind the upper to avoid interference. When two sections or two floors are being mined close to each other, it is desirable to arrange the work so that they can be shot down at the same time. Otherwise the jar and pressure adjustments caused by one coming down may cause the other to drop before it is intended. Manways in the raises will be maintained for bringing in timber and for entrance to the stope, thus giving at least two exits from each working place and aiding ventilation as well. It is believed that in these stopes both shifts can drill, blast, muck out, and timber a 5-foot cut across the stope.



Notes: 900' level drifts and raises shown in broken lines
1000' " " " " " " solid "
Arrows from raises indicate branches
Interior ore outline on 900' level shows the central core of waste
Cross-hatched areas are cut-and-fill stopes laid out on both levels.

Figure 29.- Typical haulage and development levels, Colorada mine

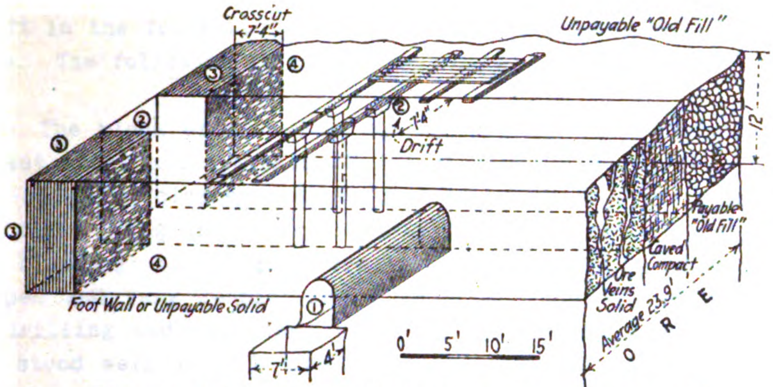


Figure 30.- Top slicing, El Bordo mine. (After Mechin, R. J., Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 139-145)

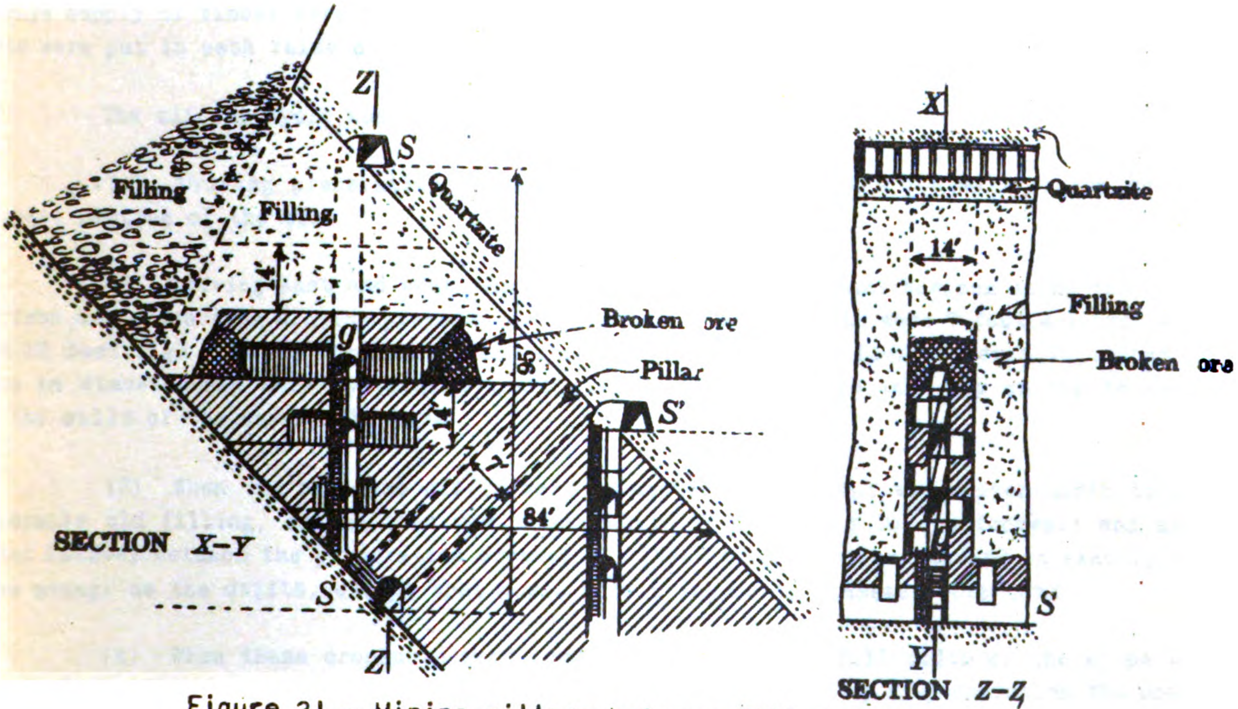


Figure 31.- Mining pillars between filled stopes working from top downward; Krivoy-Rog, Russia

2. Pachuca.- Top slicing was introduced at the El Bordo mine in 1917[24] for mining a block of ore left in the footwall by former operators which was of too low a grade to be mined at that time. The following is an abstract of Mechin's paper:

> The block of ore mined by top slicing was 295 feet long, 13 to 36 feet wide, and averaged 23.9 feet wide. The dip was 85°. The ore was of three classes, named in order from foot to hanging wall: (1) Solid ore lying on the footwall of the vein, which required drilling and blasting; (2) compact ore, probably formed by pillars left in old stopes and very compact caved material, some parts of which required drilling and blasting, while the part that could be mined by picking stood well in a 12-foot slice at 85°; (3) old filling, which was largely mineralized material caved off the hanging wall and vein material left in the old stopes, and was comparatively loose. Over most of the block, the hanging wall of the vein was not exposed, and unpayable old filling lay between it and the block mined. The true hanging and foot walls of the vein were hard andesite (fig. 30).

The block was developed by two counter drifts, one on the 1000-foot level and one on the 1197-foot level, which were connected by five 4 by 7 foot raises in the footwall, spaced 65.6 feet apart. Three crosscuts spaced at 48-foot intervals were driven from each raise to the solid hanging wall. The sill floor on the upper level was mined out by square-setting, using spiling where necessary. Sills were laid 3-1/2 feet apart and covered with a heavy floor upon which was a covering of old timber. The part not already crushed was then caved by blasting the posts. Before starting to slice, timber stations large enough to hold a days supply of timber were cut on the upper level in front of each raise. Permanent chute sets were put in each raise at the lower level.

The slicing cycle was as follows:

(1) Driving preparation crosscuts 3 by 5 feet from the footwall raises to the compact section of the ore.

(2) Driving east and west (longitudinally) in the compact horizon along the solid horizon and connecting all the preparation crosscuts. These drifts were 7 feet 4 inches wide and 12 feet high (the sublevel interval) and were timbered with 11-foot posts 10 inches or more in diameter and were set 4 feet apart with a short 10 by 10 inch cap on top to catch up the sills of the caved sub above.

(3) When two of these drifts were connected, a crosscut was driven north to the unpayable old filling, and another was driven south in the solid to the footwall and at a point halfway between the preparation crosscuts. These crosscuts were worked in exactly the same manner as the drifts, except that posts 6 to 8 inches in diameter were used.

(4) When these crosscuts were completed, a face the full width of the stope was mined, retreating from the hanging wall side toward the raises. In this operation the posts were put in 4 feet in the clear from north to south. Sills were 2-1/2 by 10 inch plank, 13 feet long, laid double with an overlap of 1 foot on the ends and covered with 2-1/2 by 8

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[24] - Mechin, R. J., Top Slicing in Old Fills at El Bordo Mine, Mexico: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 139-145.

inch by 13-foot plank which was fitted around the posts. Before caving a slice all posts possible were recovered for reuse. The post timbers recovered amounted to about 5 to 8 per cent of all posts put in. The posts were drilled with a 1-1/4-inch hole before being sent into the mine.

The ore was shoveled by hand into wheelbarrows and wheeled to the chute raises. Tons produced per man employed in stoping were: Stope preparation 0.40, actual stoping 3.38, total 3.14. Timber consumption was 7.1 board feet of sawed timber and 4.5 board feet of round timber per ton.

3. Charcas, San Luis Potosi.- Top slicing with filling of slices has been used at the Charcas Unit of the Cia. Minera Asarco S. A.[25] to mine partly worked-out sections of the mine as well as the very heavy ground in most of the stopes opened in virgin ore. The ore shoot is about 1,400 feet long in a fissure with an average dip of 70°. The footwall varies from strong limestone to broken metamorphosed limestone which requires heavy timbering. In some sections it is an altered, crumbly porphyry which swells badly. The hanging wall is a shattered and altered monzonite porphyry. The stoping width varies from a few feet to more than 90 feet and averages about 30 feet.

The method employed is stated to have the following advantages over square-setting: (1) Greater safety for the workmen, (2) better total recovery and cleaner mining, and (3) lower cost per ton mined.

The stopes are developed by two-compartment raises spaced 100 feet apart which are driven from a footwall tramming drift, and leave a 6-foot pillar between the raises and the vein.

The top floor or slice is mined by square-setting without any sills under the posts. As the square-setting proceeds, sills 10 feet long or longer are laid between the posts from foot to hanging wall and are placed on 5-foot centers. A floor of 2-inch plank is laid on these sills. As flooring is laid, the square-sets are back-filled as closely as possible with waste.

After complete mining and filling of the square-set floor, a crosscut to the vein is started from the ore pass 12 feet below the floor from which a narrow drift is driven along the footwall of the vein for 50 feet in each direction to connect with the raises on either side and to develope the next slicing level. This drift is usually driven 12 feet high with two posts at 5-foot intervals catching up the sills of the floor above.

From this drift, slices 5 feet wide are driven toward the hanging wall, using pairs of posts on 5-foot centers to catch up the sills of the floor above. The method is illustrated in plan in Figure 32A. The method differs from the usual top slicing system in that (1) the slices are back-filled as they advance, (2) posts and headblocks are used instead of drift sets to catch up the floor above, (3) since the slices are filled the timbers are not blasted out. Waste for filling is obtained by connecting the footwall drift with the waste pass as shown, the floor of the connecting crosscut being 6 feet above the bottom of the slice (fig. 32B). As the slices advance sills are laid and floored as on the top floor, and the waste filling is placed on this floor. Successively lower floors are worked in the same manner.

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[25] - Willey, Howard, Top Slicing with Filling of Slices, as Used at the Charcas Unit of the Cia Minera Asarco, S. A.: Tech. Pub. 364, Class A, Metal Mining, No. 41, Am. Inst. Min. and Met. Eng., 1930, 17 pp.

Cost savings per ton with this method as compared with square-setting are as follows:

	Mining in virgin ore	Mining in old workings
Labor	$0.106	$0.102
Explosives	.008	.011
Lumber and timber	.411	.270
Total saving by use of filled top-slice stoping at Charcas	$0.525	$0.383

Production per man-shift is approximately the same as for square-set work, viz:

	Virgin ore, metric tons	Old workings, metric tons
Square-set	1.55	1.24
Filled top slice	1.44	1.34

The recovery of ore by the filled top-slice method is estimated to be practically 100 per cent as against an estimated recovery of 95 per cent by square-setting with back filling.

PILLAR RECOVERY

As stated at the beginning of this paper, top slicing has an important application for the mining of pillars between filled stopes previously mined by other methods.

A good example of this use of top slicing is the practice at Franklin, N. J.[26]

Top slicing has been employed for mining pillars between filled stopes in the Russian iron ore mines (fig. 31).[27] Here the method is more like sublevel caving, however.

Thin floor pillars are sometimes recovered by top slicing in the Porcupine district of Ontario.[28]

UNDERGROUND OPERATING COSTS

In any discussion of mining costs as between different mines or different methods of mining, it must be borne in mind that costs are influenced by a number of factors related closely to the physical characteristics of the ores and enclosing rocks; depth of deposits below surface; size, shape, and dip of the ore bodies; amount of water handled, etc. Economic conditions and management are important factors in determination of mining costs also.

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[26] - Hodgkinson, H. H., Mining Ore from Pillars: Eng. and Min. Jour., vol. 102, No. 5, July 29, 1916, pp. 217-219. Haight, C. M., and Tillson, B. F., Zinc Mining at Franklin, N. J.: Trans. Am. Inst. Min. and Met. Eng., vol. 57, 1918, pp. 801-811, illustrated.

[27] - Jackson, Chas. F., Shrinkage Stoping: Bureau of Mines Information Circular 6293, 1930, p. 30.

[28] - Jackson, Chas. F., Work cited, pp. 14-15.

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Since no two mines will be found with the same combinations of conditions, direct comparison between costs at two different mines is bound to be misleading and unfair if the conditions at each are not thoroughly understood.

Average costs at a number of mines are also somewhat misleading, as there is no average mine. If, however, enough mines using the same method of mining be grouped together and the different items entering into the cost be analyzed in the light of a knowledge of the mining conditions, fairly reliable deductions may be drawn.

In the following pages cost data are briefly discussed under the following captions: (1) Development. (2) Costs per ton in dollars and distribution of costs in percentages of total underground cost. (3) Labor costs expressed in man-hours per ton and tons per man-shift. (4) Explosives consumption per ton of ore hoisted. (5) Timber consumption per ton of ore hoisted. (6) Kilowatt-hours consumed per ton of ore hoisted.

In the tables appended hereto the figures for iron mines are based upon the gross ton of 2,240 pounds while for the other mines they are based on the short ton, so that the figures favor the latter by roughly 10 per cent.

Development Costs (Table 1.- In this table, which includes a list of iron mines selected to be representative of the principle types of deposits, "stope development" includes only raises and sublevel drifts. The figures for stope development vary considerably because of differences in (1) type of ore body, (2) mining system or variation of the method, (3) development plan, length of slices, and sublevel interval.

Mines 1, 2, and 3 are in thin, flat ore bodies, whereas mines 4 and 5 are slightly dipping ore bodies a few subs thick. It will be noted that the tonnage per foot of stope developed for the first three mines is much greater than for mines 4 and 5. This is due to the fact that in mines 1, 2, and 3 much of the ore is mined out in one high slice 12 to 18 or even 20 feet high, and also because they are mined in long slices, whereas the older mines 4 and 5 were originally developed for hand-loading and are mined with shorter slices. Longer slices would not stand so well in mines 4 and 5 because of the greater weight of gob above them.

Mines 6 to 20 are all deeper than mines 1 to 5, greater weight has to be supported, and sublevel intervals are lower except where sublevel caving is employed. Mine 6 is an old mine developed originally for hand-loading, with tramming drifts spaced 50 feet apart; only 41 tons are developed per foot of stope development. On the new levels, raises and subdrifts are being spaced further apart, which will result in a much larger tonnage being developed per foot of stope development.

At four mines using radial top slicing, the average tonnage per foot of stope development is 66, whereas for five mines using parallel top slicing and scraping into cars the average is 61. If the same average height of slice could be used in the mines using radial slicing as in the mines scraping into cars, the figure would be 80 tons, which would show a decided saving in stope development in favor of radial slicing. However, the figures for the six mines employing parallel slicing and scraping direct to chutes show an average of 103 tons per foot of stope development. For slices of an average height equal to that for mines 1 to 5 the figure would be 131 tons. Mine 16 offers a good comparison between top slicing and sublevel caving as regards stope development, since both methods are used. With sublevel stoping 120 tons are developed per foot of stope development, whereas with top slicing only 70 tons are developed.

Contrary to what might be expected, mines 11, 12, and 13 which employ parallel top slicing and scraping to chutes, give a better tonnage per foot of stope development than mines 19 and 20 which use sublevel caving. Mines 11, 12, and 13, however, use a long slice which materially cuts down the development per ton while mine 20 is in a comparatively narrow ore body where transverse slices must be employed to give the required number of working places and because of better stope support and control of gob by driving the slices in this way. Since the ore body is narrow, the slices are short. At mine 19 the development on the lower levels is being planned for a higher sublevel interval and wider spacing of haulage drifts (which will decrease the footage of raises and timber drifts also), and this change will materially increase the tonnage developed per foot of stope development.

The figures in the last two columns of Table 1 show the tons developed per foot of total development and the feet of total development per ton developed. Total development includes both main level and stope development. The amount of main level development is influenced to a large extent by the geological occurrence of the ore bodies as well as by the stoping or slicing system employed and the distance between main levels. Thus a mine in which the ore occurs in a number of disconnected small lenses or bodies would require a proportionately greater amount of main level development than where there is one large, continuous ore body.

Based on the observations and study of the author, it is suggested that a careful analysis of development costs and of different methods of development by mine operators might be well worth while, although it is conceded that in some soft ore mines the cost of ore produced by development may be little more than that produced in stoping operations.

Costs in Dollars and in Percentages of Total Direct Operating Costs (Tables 2, 3, 4, and 5).- Tables 2 and 3 show the costs at several typical mines employing top slicing and sublevel caving, and Tables 4 and 5 show distributions of various cost items in percentages of total direct mining cost. Dollar costs in the form presented in these tables are available from too few mines for the purpose of close cost analysis. The mines listed, however, are average mines. A few top slice mines probably have a mining cost around or below a dollar per ton; more will average about $1.25 per ton.

The first six mines (Table 2) are iron mines, costs are on the long ton basis, and are given for recent years. The next three mines are copper mines with costs based on the short ton for the years 1916 and 1917. The last mine is a gold-silver mine, for which costs are figured on the short-ton basis. Thus direct comparison between the first six mines and the last four should not be made.

Mines 17 and 18 using sublevel caving show a higher total mining cost per ton than the mines employing top slicing, but a materially lower stoping cost. The item "timbering" for mines 17 and 18 is mostly for timbering in connection with development and maintenance. Mines 1, 9, 10, and 15 show mining and timbering costs combined; but mine 1 requires practically no timbering in drifts or for maintenance, whereas mines 9, 10, and 15 require varying amounts of timbering for this work, which however, is probably much less than for mines 17 and 18. Mines 17 and 18 cover large areas and are deep; mine 17 in particular is working a number of scattered ore bodies, under conditions making for high development and transportation costs.

Referring to Table 3, it will be noted that the cost of timber is appreciably lower for mines 17 and 18 which employ sublevel caving than for the top slice mines, despite the fact that they require a large amount of timber for maintenance and development. The large amount of rock development required at mine 17 is reflected principally in the cost for compressed air, drills, and steel, in the explosives cost, and in the labor cost. Mine 22 is a copper mine; the distribution of costs for this mine for 1916 have been estimated in part by the author of the present paper according to information from the original article on this operation by E. G. Deane.[29]

Tables 4 and 5 showing distribution of costs in percentages serve to emphasize the marked effect of different mining conditions on costs. Thus it will be noted that mines 1, 2, 3, 4, 5, and 6, in wide ore bodies on the Mesabi Range have a very low proportion of the total cost chargeable to development as compared to mines 10, 11, 12, 17, 18, and 20 in narrower, steeply dipping, deep ore bodies on the other ranges. The effect of scattered workings in several ore bodies is shown in the relatively high percentage for haulage at mines 7, 10, 11, 12, 13, 17, and 18. In Table 5 a low percentage of cost for timber at mines using sublevel caving as compared to top slicing is indicated.

Labor Costs in Man-Hours per Ton (Tables 6 and 6-a).- Table 6 shows the man-hours per ton of ore hoisted, distributed among the principal underground operations at a number of typical mines. The average man-hours per ton stoping for mines 1 to 14 using top slicing is 0.554 (14.6 tons per 8-hour man-shift). The average for stoping at mines 17, 18, and 20 employing sublevel caving is 0.376 man-hours of stope labor per ton (21.28 tons per 8-hour man-shift).

The average man-hours per ton for tramming, haulage, and hoisting at mines 1 to 20, inclusive (except mines 15 and 19), is 0.203 (39.4 tons per 8-hour man-shift).

Mines 17 and 18 show a high labor charge (Development column) due to the large amount of main level and exploratory development required.

It is believed that enough mines are listed in this table to give a fair idea of the labor distribution in typical top-slice mines. Some are known to have a better "tons per man" output than those listed in Table 6.

Table 6-a lists a much larger number of mines and is comprehensive enough to give a fair average of man-hours per ton required for top slicing and sublevel caving and to show the variation in labor costs per ton under different conditions.

This table shows an average tonnage per man-shift underground of 8.25 for top slicing and 8.52 for sublevel caving, while for total underground and surface labor the figures are 6.45 and 6.00 tons per man, respectively.

Explosives Consumption (Table 7).- Table 7 shows the explosives consumption per ton of ore hoisted for stoping only, development only, and the total consumption at a group of representative mines.

Timber Consumption (Table 8).- Table 8 shows timber consumption per ton of ore hoisted at a number of typical mines. It also shows the variation in practice at different mines as to sublevel interval, height and width of sets, and in the method of covering sides and bottoms of slices before blasting down or caving back.

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29 - Deane, E. G., The Block Method of Top Slicing of the Miami Copper Co.: Trans. Am. Inst. Min. and Met. Eng., vol. 55, 1916, pp. 240-244.

Kilowatt-Hour Consumption (Table 9).- Table 9 shows the power consumption at a number of representative operations, divided between air compression, hoisting, haulage and lighting, scraping, pumping, ventilation, and miscellaneous. The small amount of power required for scraping is of decided interest and should be enlightening to operators possessing a limited experience with scraper loading. These figures agree closely with data on power for scraper-loading at mines employing other stoping methods.[3]

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30 - Jackson, Chas. F., Shrinkage Stoping: Bureau of Mines Information Circular 6193 1929, Table 5, p. 30.

Table I.- Development costs

Mine	Mining system	Sublevel interval, feet	Stope development		Total development	
			Tons developed per linear foot	Linear feet of development per ton developed	Tons developed per linear foot	Linear feet of development per ton developed
No. 1	Parallel top slicing, scraping to cars	Mostly single sub.12	90	0.0111	80	0.0125
No. 2	do.	Mostly single sub	99	0.0101	86	0.0116
No. 3	do.	Mostly single sub	48	0.0209	—	—
No. 4	do.	14	36	0.0278	34	0.0294
No. 5	do.	13	34	0.0294	29	0.0345
No. 6	Radial top slicing, to chutes	12	41	0.0242	—	—
No. 7	do.	12½	64	0.0156	—	—
No. 8	do.	11	90	0.0110	60	0.0167
No. 9	Parallel top slicing, scraping into chutes	11	70	0.0143	57	0.0174
No. 10	Radial top slicing, to chutes	10	70	0.0143	—	—
No. 11	Parallel and radial top slicing, scraping into chutes	10	164	0.0061	95	0.0105
No. 12	Parallel top slicing, scraping into chutes	11	114	0.0088	85	0.0118
No. 13	do.	10	164	0.0061	130	0.0077
No. 14	do.	12	38	0.0260	30	0.033
No. 16	Sublevel caving,	20	120	0.0083	84	0.0119
	parallel top slicing, scraping into chutes	12	70	0.0143	56	0.0179
No. 19	Sublevel caving	20	100	0.0100	85	0.0120
No. 20	Sublevel caving	18	58	0.0172	49	0.0203
Average for top slicing - 15 mines			79	0.0160	—	—
Average for parallel top slicing, scraping to cars, - 5 mines			61	0.0199	—	—
Average for radial top slicing to chutes. - 4 mines			66	0.0163	—	—
Average for parallel top slicing to chutes - 6 mines			103	0.0126	—	—
Sublevel caving - 3 mines			93	0.0118	—	—

Table 2.- Direct mining costs per ton of ore hoisted

Mine and year	Mining system	Development	Mining (stoping)	Timbering	Transportation underground	General underground	Surface costs applicable to underground	Total
No.1,1929[1]	Parallel top slicing, scraping to cars	None	($0.729	———)	$0.128	$0.250	$0.058	$1.165
No.9,1929[1]	Parallel top slicing, scraping into chutes	$0.052	($0.739	———)	.210	.090	.004	1.095
No.10,1928[1]	Radial top slicing	.251	(.707	———)	.149	.193	.066	1.366
No.15,1927[1]	do.	-	(.611	———)	-	-	-	-
No.17,1929[1]	Sublevel caving	.317	.398	$0.279	.408	.135	-	1.537
No.18,1928[1]	do.	.254	.360	.224	.155	.276	.070	1.339
No.21,1917[2]	Inclined top slicing	-	(.750	———)	-	-	-	-
No.22,1916[2]	Top slicing in blocks hand-shoveling	.140	.350	.200	.095	.065	.030	.880
No.23,1916[2]	Mitchell top-slice, caving	-	(.930	———)	-	-	-	-
No.24,1925[2]	Top slicing, hand-shoveling	-	(.78	———)	-	-	-	-

1 - Calculations made on Long-ton basis. 2 - Calculations made on Short-ton basis.

Table 3.- Direct mining costs per ton of ore hoisted

Mine and year	Mining system	Labor and supervision	Air, drills and steel	Power cost	Explosives	Timber	Other supplies	Total
No. 1,1929[1]	Parallel top slicing, scraping to cars	$0.710	$0.026	$0.092	$0.060	$0.144	$0.133	$1.165
No. 9,1929[1]	Parallel top slicing, scraping into chutes	.633	.100	.057	.062	.082	.161	1.095
No. 10,1928[1]	Radial top slicing	.781	.092	.141	.093	.105	.154	1.366
No. 17,1929[1]	Sublevel caving	.927	.134	.143	.128	.068	.137	1.537
No. 18,1928[1]	Sublevel caving	.808	.091	.150	.093	.060	.077	1.279
No. 22,1916[2] [3]	Top slicing in blocks hand-shoveling	.528	.045	.064	.065	.130	.048	.880

1 - Calculations on long-ton basis. 2 - Calculations on short-ton basis. 3 - Distribution estimated in part by author from original paper.

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Table 4.- Distribution of direct mining costs in percentages of total direct mining cost

Mine	Mining system	Percentages of total direct mining cost								
		Development	Mining (stoping)	Timbering	Haulage, underground	Hoisting, underground	Pumping	General, underground	Surface applicable to underground	Total
No.1,1929	Parallel top slicing, scraping to cars	(———	62.6	——)	(11.0	——)	(21.5	———)	4.9	100
No.2,1929	do.	12.2	40.9	25.6	12.0	2.2	1.3	5.8	—	100
No.3,1929	do.	None	(88.6	——)	6.8	2.2	1.2	1.2	—	100
No.4,1929	do.	8.0	(77.7	——)	5.0	2.7	4.2	2.4	—	100
No.5,1929	do.	0.7	(80.6	——)	6.8	4.7	0.6	6.6	—	100
No.6,1929	Radial top slicing	3.6	53.4	28.5	5.8	2.5	1.0	5.2	—	100
No.7,1929	do.	2.7	37.9	35.8	11.7	7.9	1.2	2.8	—	100
No.8,1929	do.	7.7	(59.4	——)	8.0	4.3	15.0	5.6	—	10
No.9,1929	Parallel and radial top slicing, scraping into chutes	4.8	(67.5	——)	12.0	7.2	8.0	0.5	—	10
No.10,1928	Radial top slicing	18.4	(51.7	——)	10.9	———)	(14.1	———)	4.9	10
No.11,1929	Parallel top slicing, scraping into chutes	10.5	(66.4	——)	11.2	5.6	4.4	1.9	—	10
	do.	8.9	(60.4	——)	11.5	6.9	11.5	0.8	—	10
No.13,1929	do.	3.2	(68.9	——)	10.9	11.0	4.9	1.1	—	10
No.14,1929	do.	11.2	(45.3	——)	4.3	2.2	32.7	4.3	—	10
No.16,1929	Sublevel caving and parallel top slicing scraping into chutes	5.0	(60.0	——)	9.0	12.0	3.5	10.5	—	1
No.17,1929	Sublevel caving	20.6	25.9	18.2	(26.6	———	———	———)	8.7	1
No.18,1928	do.	19.0	26.9	16.7	(11.6	——)	(20.6	———)	5.2	1
No.20,1929	do.	11.8	43.0	19.6	9.9	8.9	2.0	4.8	—	1
No.22,1916	Top slicing in blocks hand-shoveling	15.9	39.8	22.7	6.3	4.5	0.6	7.4	2.8	1

Table 5.- Distribution of direct mining costs in percentages of total direct mining cost

Mine	Mining system	Percentages of total direct mining cost						
		Labor and supervision	Air, drills and steel	Power cost	Explosives	Timber	Other supplies	Total
No.1,1929	Parallel top slicing, scraping to cars	60.9	2.2	7.9	5.2	12.4	11.4	100.00
No.2,1929	do.	67.3	—	3.6	—	—	29.1 All supplies	100.00
No.3,1929	do.	60.3	—	5.5	—	—	34.2 All supplies	100.00
No.4,1929	do.	64.9	—	6.8	—	—	28.3 All supplies	100.00
No.5,1929	do.	67.1	—	6.2	—	—	26.7 All supplies	100.00
No.6,1929	Radial top slicing	70.4	2.1	4.5	8.7	10.2	4.1	100.00
No.7,1929	do.	68.7	—	4.5	—	—	26.8	100.00
No.8,1929	do.	59.4	—	14.0	—	—	26.6 All supplies	100.00
No.9,1929	Parallel top slicing, scraping into chutes	57.9	9.1	5.2	5.7	7.5	14.6	100.00
No.10,1928	Radial top slicing	57.2	6.7	10.3	6.8	7.7	11.3	100.00
No.11,1929	Parallel and radial top slicing, scraping into chutes	66.0	—	9.4	—	—	24.6 All supplies	100.00
No.12,1929	Parallel top slicing, scraping into chutes	57.7	—	18.1	—	—	24.2 All supplies	100.00
No.13,1929	do.	55.3	—	10.7	—	—	34.0 All supplies	100.00
No.14,1929	do.	55.6	—	27.4	—	—	17.0 All supplies	100.00
No.16,1929	Sublevel caving and parallel top slicing, scraping into chutes	64.0	—	1.4	—	—	34.6 All supplies	100.00
No.17,1929	Sublevel caving	60.3	8.7	9.3	8.4	4.4	8.9	100.00
No.18,1928	do.	63.2	7.1	11.7	7.3	4.7	6.0	100.00
No.20,1929	do.	69.3	—	8.8	—	—	21.9 All supplies	100.00
No.22,1916	Top slicing in blocks	60.0	5.1	7.3	7.3	14.8	5.5	100.00

Table 6.- Labor costs in man-hours per ton

Mine and year	Man-hours per ton of ore hoisted							Tons per 8-hour man-shift	
	All stope labor	Tramming, haulage, hoisting	General labor	Supervision	Total underground labor, except development	Development labor	Total underground labor	All underground except development	All underground labor
No.1,1929	[1]0.619	0.184	0.189	0.076	1.068	-	1.068	-	7.49
No.2,1929	.515	.260	(.179	———)	.954	0.200	1.154	8.39	6.93
No.3,1929	.585	.086	(.060	———)	.731	None	.731	-	10.94
No.4,1929	[1].540	.082	(.155	———)	-	-	.777	-	10.30
No.5,1929	.617	.224	(.145	———)	.886	.007	.993	9.02	8.06
No.6,1929	.645	.252	(.154	———)	1.051	.076	1.127	7.61	7.01
No.7,1929	.401	.314	(.488	———)	1.163	.100	1.263	6.88	6.34
No.8,1929	.446	.193	(.210	———)	.849	.123	.972	9.42	8.23
No.9,1929	.533	.155	.095	.029	.812	.091	.903	9.85	8.87
No.10,1928[2]	.354	.196	.102	.034	.686	.343	1.029	11.65	7.77
No.11,1929	.919	.247	(.130	———)	1.296	.090	1.386	7.72	7.22
No.12,1929	.556	.205	(.142	———)	.903	.145	1.048	8.86	7.63
No.13,1929	.695	.222	(.074	———)	.991	.027	1.018	8.07	7.68
No.14,1929[2]	.335	.106	(.230	———)	.671	.151	.822	11.92	9.72
No.16,1929	.636	.169	(.261	———)	1.066	.127	1.193	7.50	6.70
No.17,1929	.411	.226	.105	.061	.803	.594	1.397	9.96	5.72
No.18,1928	.352	.326	.133	.045	.856	.480	1.336	9.34	5.98
No.20,1929	.365	.214	(.192	———)	.771	.200	.971	10.26	8.24
No.21,1917[3]	1.481	-	-	-	-	-	-	-	-
1919[4]	.909	-	-	-	-	-	-	-	-
No.22,1916	.800	-	-	-	-	-	-	-	-
No.24,1925	2.250	-	-	-	-	-	-	-	-

Note: Mines 1 to 20 are iron mines; calculations are on long-ton basis. Figures for mines 21 to 24 are on short-ton basis.

[1] Includes development.

[2] Some sublevel stoping (open stopes) included.

[3] Flat top slicing, hand-shoveling.

[4] Inclined top slicing.

Table 6-a.- Costs in man-hours per ton for group of mines using top slicing and sublevel caving, 1929

1. Top slicing

Mine	Gross tons	Man-shifts underground	Man-hours per ton underground	Tons per man-shift underground	Man-shifts on surface	Tons per man-shift underground and on surface
M-A	337,735	30,184	0.715	11.18	7,084	9.06
M-B	197,459	14,150	0.573	13.95	4,245	10.58
M-C	406,200	49,014	0.965	8.29	19,459	5.93
M-D	315,083	30,591	0.777	10.29	8,343	8.10
M-E	173,323	17,825	0.823	9.72	7,047	4.97
M-F	198,577	18,100	0.729	10.97	6,341	8.12
M-G	47,039	6,945	1.179	6.77	1,067	5.87
M-H	243,582	20,064	0.659	12.14	3,952	10.14
M-I	293,382	35,373	0.965	8.29	8,008	6.76
M-J	347,510	35,669	0.821	9.74	16,503	6.66
M-K	777,100	97,710	1.005	7.95	21,370	6.53
M-L	209,300	26,502	1.013	7.89	1,442	7.49
M-M	388,625	56,898	1.171	6.83	21,485	4.96
M-N	100,684	17,078	1.357	5.89	2,179	5.23
C-O	211,460	25,690	0.972	8.23	inc. with underground	8.23
C-P	218,928	20,596	0.753	10.63	7,393	7.82
V-Q	897,658	114,938	1.024	7.81	34,352	6.01
V-R	406,400	69,842	1.375	5.82	19,127	4.57
M-S	343,147	42,259	0.985	8.12	12,766	6.24
M-T	275,000	33,709	0.980	8.16	13,256	5.86
M-U	91,374	11,656	1.020	7.93	8,680	4.49
M-V	331,900	49,000	1.181	6.77	13,140	5.34
M-W	555,919	62,749	0.903	8.86	15,220	7.13
M-X	311,821	36,845				
M-Y	136,334	31,991	1.877	4.26	11,022	3.17
M-Z	250,000	21,631	0.692	11.56	8,954	8.17
Totals and averages	8,065,540	977,009	0.969	8.25	272,435	6.45

Table 6-a.- Costs in man-hours per ton for group of mines using top slicing and sublevel caving, 1929 - Continued

2 Sublevel caving

Mine	Gross tons	Man shifts underground	Man-hours per ton underground	Tons per man-shift underground	Man-shifts on surface	Tons per man-shift underground and on surface
C-A	320,000	35,160	0.879	9.10	6,240	7.73
C-B	252,000	32,040	1.017	7.87	9,360	6.09
V-C	347,610	39,535	0.909	8.79	14,015	6.49
M-D	112,820	16,985	1.204	6.64	8,085	4.50
G-A	401,670	70,350	1.401	5.71	20,330	4.43
G-B	681,900	77,065	0.904	8.85	37,520	5.95
G-C	450,000	69,075	1.228	6.52	6,075	5.98
G-D	636,000	58,050	.730	10.96	36,300	6.74
G-E	1,272,000	179,180	1.127	6.07	90,250	4.73
G-F	410,700	34,160	0.665	12.02	24,155	7.04
G-G	380,300	36,200	0.761	10.51	21,355	6.60
G-H	620,000	42,640	0.550	14.54	16,420	10.50
Totals and averages	5,885,000	690,440	0.938	8.52	290,105	6.00

Table 7.- Explosive consumption per ton of ore hoisted

Mine and year	Explosive used		Pounds explosive per ton ore hoisted		
	Kind	Strength, per cent	Development	Stoping only	Total
No. 1, 1929	R. C. and gelatin	40	None	0.395	0.395
No. 2, 1929	Special gelatin	(35	0.184	.601	.785
		40-60	.016	-	.016
				Total	.801
No. 3, 1929	Red Cross	40	None	.694	.694
No. 4, 1929	Gelatin	35	-	-	.463
No. 5, 1929	R. C. and special gelatin	(30		.530	.530
		(40-60	.003	-	.003
				Total	.533
No. 6, 1929	Gelatin	(35	.012	.473	.485
		(60	.016	.061	.077
				Total	.562
No. 7, 1929	Gelatin	(35	.008	.396	.404
		(50	.026	.003	.029
				Total	.433
No. 8, 1929	Red Cross	35-40-60	.087	.547	.634
No. 9, 1929	Gelatin	50-60	.036	.372	.408
No. 10, 1928	Amm. gelatin	60	.229	.244	.473
No. 11, 1929	L. F. standard	50-60	.065	.482	.547
	Amm. gelatin	60			
No. 12, 1929	L. F. gelatin	50-60	.118	.319	.437
No. 13, 1929	L. F. gelatin	50-60	.012	.353	.365
No. 14, 1929	-	-	.330	.467	.797
No. 16, 1929	Gelatin	50	-	-	.421
No. 17, 1929	Gelatin	40-60	.328	.382	.710
No. 18, 1928	L. F. gelatin	35-60	.196	.394	.590
No. 20, 1929	Red Cross	(40	.144	.553	.697
		(60	.025	-	.025
				Total	.722
No. 23, 1929	-	-	.055	.175	.230
Averages			0.111 17 mines	0.438 17 mines	0.538 19 mines

Table 8. Timber consumption per ton of ore hoisted

Mine and year	Sublevel interval feet	Length of timber, feet		Covering		Timber per ton of ore	Linear feet of poles per ton ore	Lagging
		Caps	Posts	Side	Bottom			
No. 1 1929	Mostly single sub	8–10	8–12 12–18	Hard wood boards	Boards where more than one sub	(— 2.83 bd.ft.	-	-)
No. 2, 1929	Mostly single sub	10	8–18	Wire fence	do.	— —	-	-
No. 3, 1929	Mostly single sub	10	8–18	Wire fence	do.	1.16 lin.ft. --	1.24	1.20 Cords[1] per 1000 tons
No. 4, 1929	14	8	12	Wire fence	Hard wood boards	(1.06 bd.ft —)	1.256	1.18 "
No. 5, 1929	13	10	11	Wire fence	Boards on poles	(1.336 bd.ft. —	-	1.635 "
No. 6, 1929	12	8–12	10	Wire fence	Wire fence on poles	(.96 lin.ft. —)	1.25	3.250 "
No. 7, 1929	12½	8	10	None	Wire fence on poles	— —	-	-
No. 8, 1929	11	8–12	9–10	None	Boards on poles	.746 lin.ft.	-	1.00 lin.ft. per ton
No. 9, 1929	11	9	9	Wire or boards	Plank or wire on poles	(1.121 lin.ft. —	-)	2.585 lin.ft. per ton
No. 11, 1929	10	9	8	Wire or boards	Plank or wire on poles	(1.702 bd.ft. —)	(-	3.941 lin.ft. per ton
No. 12, 1929	11	9	9	Wire or boards	Plank or wire on poles	(1.117 bd.ft. —)	1.849	4.474 lin.ft. per ton
No. 13, 1929	11	9	9	Wire or boards	Plank or wire on poles	(1.376 bd.ft. —)	(-	3.052 lin.ft. per ton
No. 14, 1929	12	10	10	Wire	Wire on 2" plank	(0.525 lin.ft.)		1.493 lin.ft.
No. 16, 1929	12 top slice 20 sub cave	10	10	None	2" plank	(1.551 bd.ft. —)		1.30 Cords per 1000 tons
No. 17, 1929	18	7	7	None	None	(3.25 bd.ft. —	-	-)
No. 18, 1928	18	8	8	None	None	(2.76 bd.ft. —	-	-)
No. 24, 1925	12	short take-up caps under sills	11	-	2½" plank on sills	7.1 bd.ft. sawed timber 4.5 bd.ft. round timber	- -	-) -)

1 - Cords of 6 foot length lagging

Table 9.- Kilowatt-hours per ton of ore hoisted

Mine and year	Kilowatt-hours per ton of ore hoisted							
	Compressed air	Hoisting	Haulage and lighting	Scraping	Pumping	Ventilation	Miscellaneous	Total
No. 1, 1929	-	-	-	-	-	-	-	4.47
No. 2, 1929	1.435	0.574	[1](0.483	-)	0.377	0.103	-	2.97
No. 3, 1929	.782	.503	.279	0.223	.074	-	-	1.86
No. 4, 1929	1.281	.316	[1](.527	-)	1.368	-	-	3.49
No. 5, 1929	2.187	.298	[1](.747	-)	.126	-	-	3.36
No. 6, 1929	1.783	.688	[1](.722	-)	.653	.317	-	4.16
No. 7, 1929	1.782	2.465	[1](.330	-)	.468	.203	-	5.25
No. 8, 1929	2.470	.770	.570	[2].280	7.360	.060	-	11.51
No. 9, 1929	4.490	2.780	[1](.600	-)	3.960	-	0.660	12.49
No. 10, 1929	4.240	[illegible].300	[1](.940	-)	1.780	-	.130	9.39
No. 11, 1929	3.700	2.850	[1](.360	-)	2.480	-	-	9.39
No. 12, 1929	6.750	2.880	[1](.540	-)	7.590	.650	-	18.41
No. 13, 1929	7.571	4.887	[1](.488	-)	2.881	.585	-	16.41
No. 17, 1929	5.630	3.910	[1] 1.410	-	4.670	-	-	15.62
No. 18, 1928	3.310	[3].620	[1] .512	-	1.800	-	-	[3]6.24
No. 19, 1929	-	-	-	[4].305	-	-	-	-
No. 20, 1929	4.663	2.593	[1](.745	-)	1.382	-	-	9.38
Averages	3.472	1.896	(.650	-)	2.464			8.40
	15 mines	15 mines	15 mines		15 mines			16 mines

[1] Includes scraping.

[2] One-half tonnage by electric tuggers, balance by compressed-air tuggers.

[3] Plus 0.32 pounds of steam for steam hoist.

[4] Based on actual metered test during loading of 51,000 tons and includes sublevel lights.

DESCRIPTIONS OF DEPOSITS

Mine 1.- Flat, broad ore body slightly dipping between taconite walls. Only one sub thick over much of the area. Average daily output was 700 tons in 1929.

Mine 2.- Broad, thin bed of ore 1,400 by 1,800 feet, dipping 10°. Ore is soft, hydrated hematite of fine texture and medium strength. Walls are taconite (ferruginous chert). Where overlying the ore, the taconite is in various stages of decomposition. Daily output averaged 1,450 tons in 1929.

Mine 3.- Broad, thin ore body only one sub thick over most of the area. Dips at 3-1/2°, with paint rock and slate hanging wall fairly solid. Average daily production 1,090 tons in 1929.

Mine 4.- Wide body of soft hematite ore averaging about 38 feet in thickness and having an average dip of 4°. The overlying and underlying rock is taconite, the former being somewhat decomposed. Daily output averaged 905 tons in 1929.

Mine 5.- Soft, hydrated hematite ore body with flat dip. The mine is approaching exhaustion and is being worked in the narrow bottom of the ore trough. The bottom of the ore is sandy, decomposed taconite and the back is taconite. Average daily output is 863 tons in 1929.

Mine 6.- Thick ore body 1,000 by 2,400 feet, dipping 6°. Ore is soft, hydrated hematite of fine texture and medium strength. Walls are taconite. Unaltered taconite is hard and strong, but the altered rock is shaly, soft, and fragile. The main level interval is 100 feet. The average daily production was 2,260 tons in 1929.

Mine 7.- Bedded deposit in tough greenstone 600 by 300 feet, dipping 60 to 80° on the limb of the ore trough. Mostly soft hematite ore but contains some hard massive ore. Wall rock is greenstone and ore bodies have a jasper capping. Ore and greenstone are separated by thin seam of paint rock. The main level interval is 100 feet. Average daily output, 3,020 tons in 1929.

Mine 8.- Ore body 10 to 75 feet wide, dipping nearly vertical. Soft to medium hard hematite ore formed by enrichment in fractured iron formation. Wall rock is iron formation grading into ore and is somewhat fractured. Hanging wall is soft and treacherous where it is wet. Main level interval, 150 feet. Average daily output, 707 tons in 1929.

Mine 9.- Large bedded deposit in trough pitching 15°, with sides dipping 45°. Soft hematite ore with bands of hard blue ore. All drifts must be timbered. One wall is well defined and the other is gradational. Footwall is slate with jasper capping and hanging wall which breaks readily. Some dikes and minor faulting. Main level interval, 100 feet. Daily production, 1,859 tons in 1929.

Mine 10.- Soft iron ore in troughs and basins formed by faults and folds in slates or between slates and dikes. Ore bodies are lenticular masses with jasper hanging and slate footwall. Main level interval, 200 feet. The daily output was about 800 tons by top slicing in 1928.[31]

Mine 11.- Bedded deposit both hard and soft hematite ore, dip 45°. Quartzite hanging wall with slabby soaprock between hanging and ore. The footwall is hard jasper. The ore body is cut up by dikes. Main level interval, 100 feet. Daily production, 682 tons in 1929.

Mine 12.- Bedded deposit of soft hematite ore with bands of hard, blue ore in a trough pitching 15° and sides dipping 45°. Does not stand on exposure to air and all openings are timbered. Slate footwall; enriched jasper hanging wall which breaks readily. Some dikes and minor faulting. Main level interval, 200 feet. Daily output, 1,137 tons in 1929.

Mine 13.- Large deposit of soft hematite ore with hard seams of blue ore under hanging wall, in a trough pitching 30° and sides dipping 45°. One wall is well defined and the other is gradational. All drifts must be timbered. Footwall is slate; hanging wall is jasper which breaks readily. Many dikes and faults cut the ore body. Main level interval, 100 feet. Daily production averaged 1,140 tons in 1929.

Mine 14.- Irregular masses of hard red hematite ore 20 to 200 feet thick, dip horizontal to 55°. Ore breaks well. Footwall composed of soft, slippery graphitic slates. Hanging wall varies from wet sand to soft and hard cherty formation. Both top slicing and sublevel stoping (open stope) are used. Average daily output 816 tons in 1929.

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[31] - Eaton, Lucien, Mining Soft Hematite at Mine No. 2 of the Marquette Range, Michigan: Bureau of Mines, Information Circular 6179, 1929 15 pp.

Mine 15.- Data appears only in Table 2. Irregular bodies of soft hematite with walls of slate and iron formation.

Mine 16.- Irregular ore bodies of both hard and soft hematite dipping at about 70°, 10 to 175 feet wide, and several hundred feet long. Walls are greenstone and capping is jasper. Side walls cave and slip badly. Both top slicing and sublevel caving are employed. Main level interval, 100 feet. Average daily output, 1,125 tons in 1929.

Mine 17.- Soft hematite ore bodies requiring timber support in all openings and dipping 55 to 75° lying on quartzite footwall and overlain by siliceous slates. Contact between cherty iron formation (capping) and ore very irregular. Mining operations now at considerable depth. Main haulage levels at 200-foot intervals. Average daily output, 1,350 tons in 1929.[32]

Mine 18.- Large and small irregularly shaped bodies of soft iron occurring in pitching troughs made by intersection of dikes with impervious members of the formation and in irregular chimneys following cross faults to great heights. Dip averages 65°. None of the ore is free-caving though it disintegrates rapidly. Footwall is hard quartzite, hanging wall is partially leached slaty iron formation. Main level interval is 125 to 300 feet. Average daily output from sublevel caving, 1,500 tons in 1929.[33]

Mine 19.- Large body of soft iron ore up to 300 feet in width, dip 65° on quartzite footwatt with irregular hanging wall composed of partly leached iron formation which is high in iron content. Main level interval, 125 feet. The rate of output is about 1,500 tons per day.

Mine 20.- Bedded deposits of soft iron ore at intersection of dykes with quartzite footwall, dipping 65°. Size 110 by 1,000 feet. Hanging wall is slate which slabs easily. Main level interval, 100 feet. Average daily output, 1,250 tons in 1929.

Mine 21.- Copper mine in Arizona.[34]
Mine 22.- Wide bodies of disseminated type copper ore in porphyry.[35]
Mine 23.- Large body of oxide copper ore in heavy, swelling ground.[36]

Mine 24.- See Mechin, R. J., Top-Slicing in Old Fills at El Bordo Mine, Mexico: Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 139-145.

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[32] - Schaus, O. M. Method and Cost of Mining Hematite at the Eureka-Asteroid Mine on the Gogebic Range, Gogebic County, Mich.: Bureau of Mines, Information Circular 6348, 1930, 13 pp.

[33] - Schaus, O. M., Mining Methods and Costs at the Montreal Mine, Montreal, Wis.: Bureau of Mines, Information Circular 6369, in press.

[34] - Mosier, McHenry, and Sherman, Gerald, Mining Practice at Morenci Branch, Phelps Dodge Corporation, Morenci, Ariz.: Bureau of Mines, Information Circular 6107, 1929, 33 pp.

[35] - Deane, E. G., The Block Method of Top Slicing of the Miami Copper Co.: Trans. Am. Inst. Min. and Met. Eng., vol. 55, 1916, pp. 240-243.

[36] - Wilson, Philip D., Stoping in the Calumet and Arizona Mines, Bisbee, Ariz.: Trans. Am. Inst. Min. and Met. Eng., vol. 55, 1917, pp. 118-136.

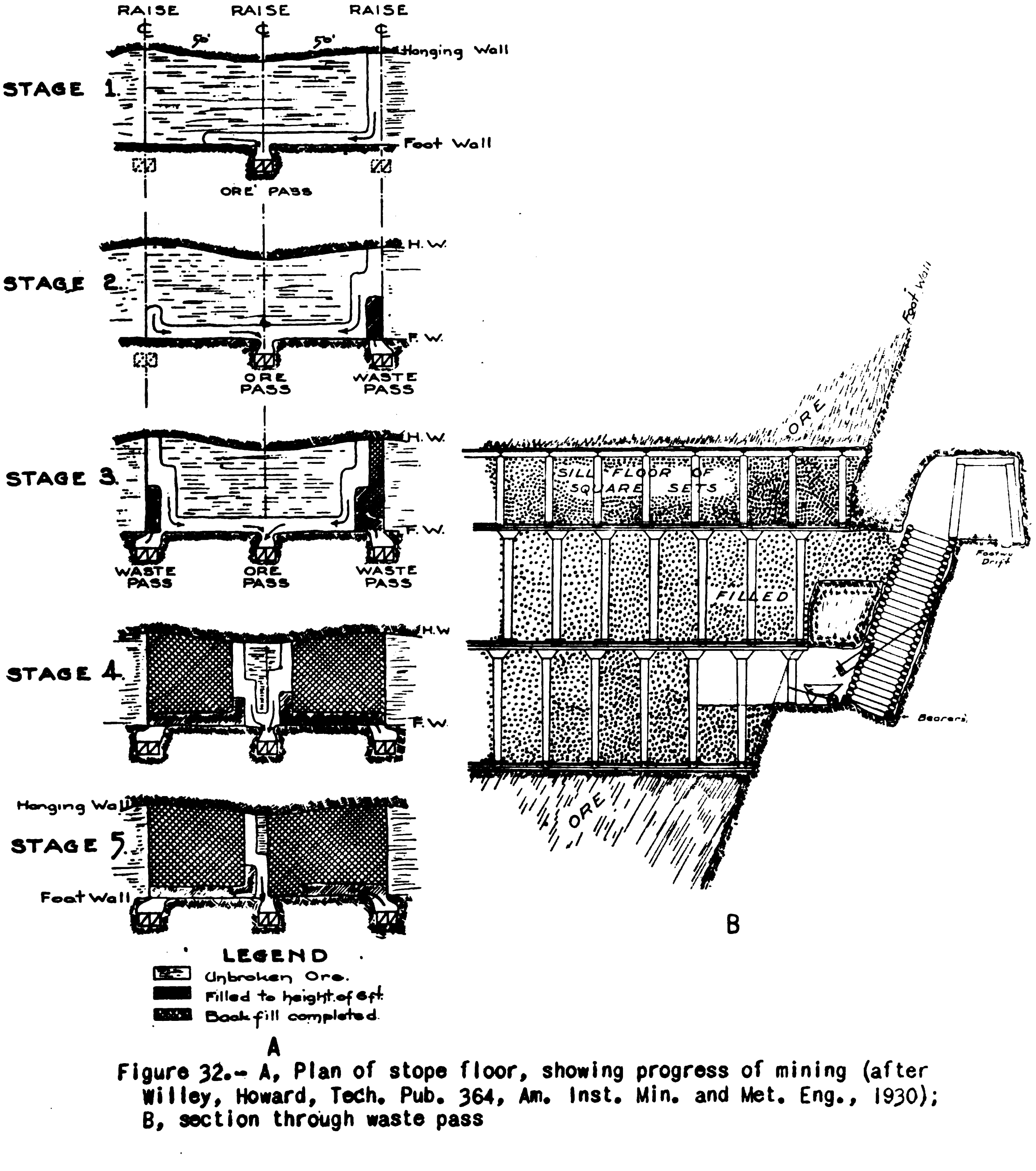

Figure 32.- A, Plan of stope floor, showing progress of mining (after Willey, Howard, Tech. Pub. 364, Am. Inst. Min. and Met. Eng., 1930); B, section through waste pass